AN INVESTIGATION OF THE USE OF MICRO COMPUTERS TO AID THE PILOT IN THE SOLUTION OF THE BALLISTICS PROBLEM

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THESIS

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by

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The advent of jet fighter/attack aircraft has resulted in the need for additional devices to aid the pilot in the accurate delivery of unguided weapons. The current generation of attack aircraft has met this need with the installation of minicomputers and additional sensor devices such as doppler radar and inertial navigation systems.

This paper demonstrates a low cost method for improving the delivery accuracy of those aircraft which do not have such devices installed. A comparison is made between delivery accuracy with and without the proposed modification.

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This paper demonstrates a low cost method for improving the delivery accuracy of those aircraft which do not have such devices installed. A comparison is made between delivery accuracy with and without the proposed modification.

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I. INTRODUCTION

The purpose of this paper is to examine the feasibility of using a micro computer in Naval aircraft to aid the pilot in the solution of the ballistics problem for unguided weapons. Specifically, this problem is to release a weapon at some point in space with the proper velocity vector so that the weapon will eventually strike a selected target. Since several models of attack aircraft (A-6E, A-7E) are equipped with computers which perform this function, special attention will be focused on those aircraft in which the pilot manually provides the solution. Such aircraft are referred to as fixed sight aircraft and the F-4 is representative of this class.

The micro computer, because of its low cost and weight, is a device with the potential to provide the pilot of fixed sight aircraft with useful and timely information. To determine whether such a potential could be exploited, the INTEL 8080 is examined as being representative of modern micro computers and the F-4 is considered as a typical fixed sight aircraft. The concepts, however, are intended to be more general in nature and no discussion , data, or conclusion contained herein is intended as an endorsement or criticism of the manufacturer or weapon systen involved.

The body of the paper consists of four major sections. The sections are as follows: a description of the general nature of the unguided weapons delivery problem and how the problem is now solved by pilots of fixed sight aircraft; the proposed use of a micro computer to aid the pilot; an

analysis and test of the proposed solution; and conclusions.

II. UNGUIDED WEAPONS DELIVERY USING FIXED SIGHT AIRCRAFT

A. DEFINITIONS

Fixed sight aircraft is a term applied to those aircraft equipped with neither a lead computing gunsight nor a computer operated bomb release device. In such aircraft a sighting device or gunsight is located in the pilot's forward field of view. Its purpose is to represent visually an angle in milliradians (mils) measured in the positive direction below a longitudinal reference line called the FUSELAGE REFERENCE LINE (FRL). Figure 1 depicts such a device. Typically these devices are adjustable through a range of zero to approximately 200 mils, but once adjusted they remain set until manually changed by the pilot.

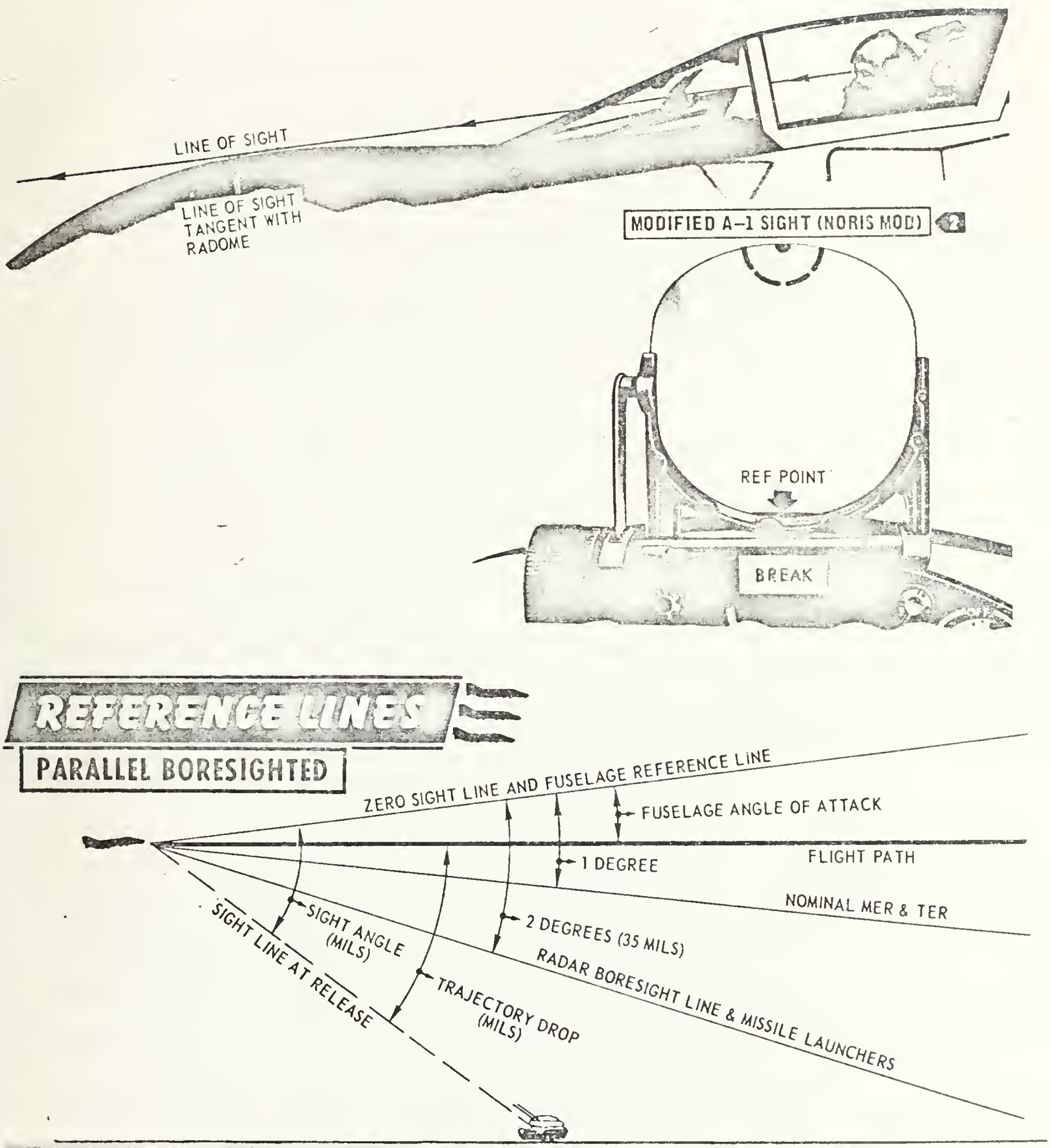


Fig 1 SIDE VIEW AND PILOT VIEW OF A GUNSIGHT

B. PROBLEM DEFINITION

For a particle of constant mass, m, moving under the action of an applied force, F, Newton's second law of motion states that

$$F=m*a. \qquad (1)$$

If the weapon is considered to be such a particle, and if the position of the weapon is measured in a rectangular coordinate system, (x,y,z), then equation (1) may be written in vector form as

$$(a_x, a_y, a_z) = (F_x, F_y, F_z)/m. \qquad (2)$$

For air to ground weapons delivery, the coordinate system is chosen so that y represents altitude, x represents the down range travel of the weapon, and the z axis measures displacement in azimuth. The origin is chosen so that, at the moment of release, x equals zero.

If it is assumed that the air mass through which the weapon is moving is stationary with respect to the earth, that gravitational forces are constant with respect to y, and that forces induced by the rotation of the earth are negligible, then $F_z=0$. The remaining forces acting on the weapon are drag, thrust, and gravitational force. It will be assumed that thrust is zero, for all weapons except rockets. Rockets are assumed to have a short initial period of constant thrust after which they fall with the same discipline as all other unguided weapons. Drag acts in the

direction opposite to the direction of the velocity vector and is directly proportional to $||V||^2$ and air density. In a standard air mass, density is a decreasing function of altitude. Therefore equation (2) may be written in component form as follows

$$a_x = -drag_x * 1/m \qquad (3)$$

$$a_y = -(drag_y + g*m)/m \qquad (4)$$

where g is a constant 32.17 ft/sec^2.

Letting $THETA=ARCTAN(v_y/v_x)$, (3) and (4) become

$$a_x = -drag*cos(THETA)/m \qquad (5)$$

and

$$a_y = -drag*sin(THETA)/m \; -g. \qquad (6)$$

Drag is represented as

$$drag=rho*S*V^2*C_d$$

where 'rho' is the air density, 'S' is the cross sectional area, 'V' is the total velocity ($(V_x^2+V_y^2)^{1/2}$), and C_d, the drag coefficient, is a dimensionless factor whose value depends on the shape of the weapon and the ratio of 'V' to the speed of sound at altitude y. Equations (5) and (6) may be considered as differential equations

$$a_x = f(v_x, v_y, x, y, t) \quad (7) \text{ and}$$

$$a_y = h(v_x, v_y, x, y, t). \quad (8)$$

In air-to-ground weapons delivery, equations (7) and (8) may be solved numerically for any set of initial conditions (v_x^0, v_y^0, x^0, y^0) to determine a time t' where $y_{t'}$=the target elevation and $x_{t'}$ is the down range travel of the weapon. Therefore, the problem for air-to-ground delivery is to position the aircraft so that the initial conditions are matched when the selected aim point is a distance $x_{t'}$ down range from the aircraft.

For unguided air-to-air weapons, equations (7) and(8) may be solved together with initial value conditions to describe the position (x(t),y(t),z(t)) of the weapon at any time t after the weapon has been fired. Since the position of the target is also some function of time, $(x_{target}(t), y_{target}(t), z_{target}(t))$, the problem is to find a set of initial value conditions such that for some time, t'',

$$(x(t''), y(t''), z(t'')) = (x_{target}(t''), y_{target}(t''), z_{target}(t'')).$$

In either case, the aircraft instruments provide the

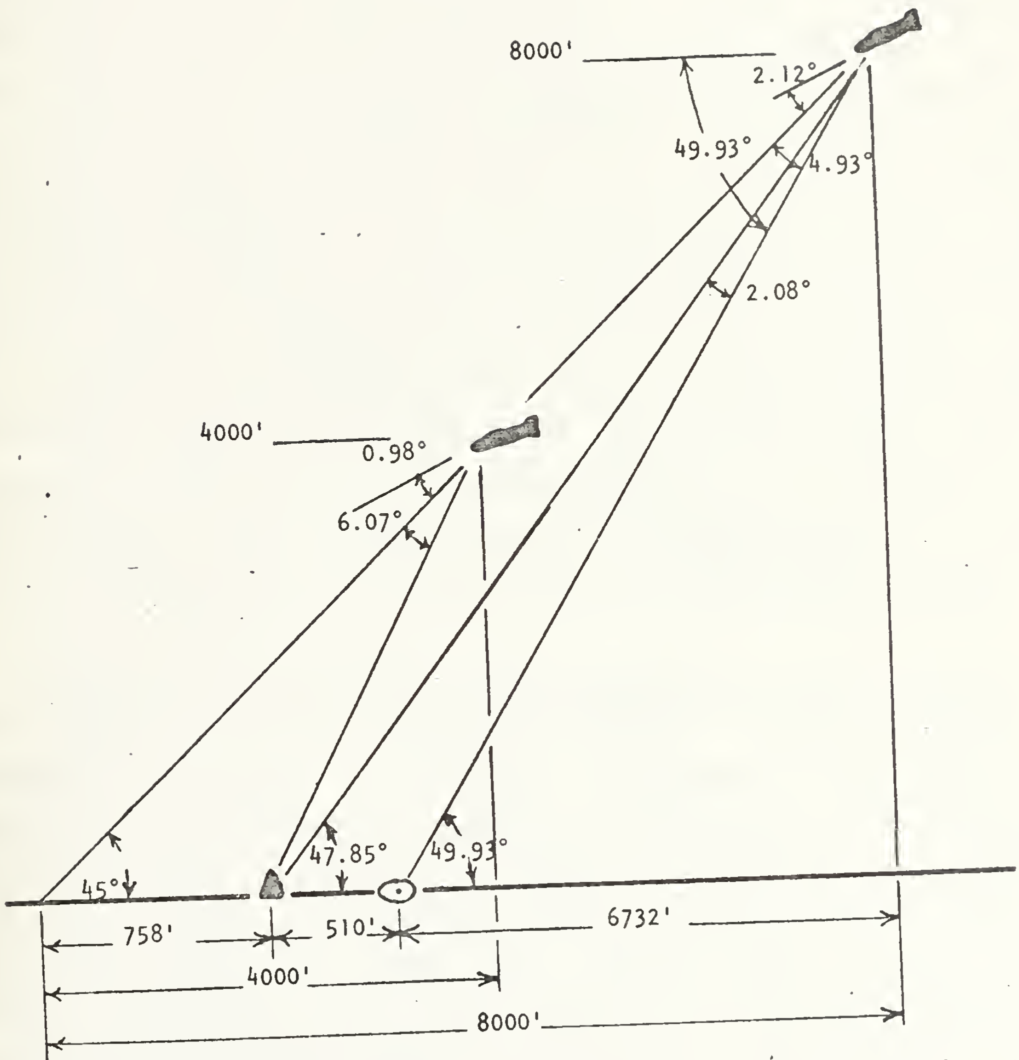
indication that the initial conditions are satisfied. The gunsight is used to establish a spatial relationship to the target. The desired terminal condition occurs at some future time when the weapon hits the target. This mixture of initial condition and terminal condition constraints makes the problem a combination initial value problem and boundary value problem.

C. PILOT SOLUTION FOR AIR TO GROUND DELIVERY

Although high speed computers which numerically solve (just prior to weapon release) equations (7) and (8) are installed on some attack aircraft (A-6E, A-7E), no such devices are installed on fixed sight aircraft. For the pilot of the fixed sight aircraft a numerical solution of the problem is not available in flight. Therefore sets of solutions have been calculated for various initial conditions. The pilot decides, prior to reaching the target, which of the precomputed sets of initial conditions he will match. Then he consults a table which contains a standard sight setting. After adjusting this setting to correct for variations in aircraft gross weight and release altitude, he adjusts his sight to this corrected value. Finally, he flies the aircraft so as to match the delivery parameters, places the sight image over the target, and releases the weapon. If all parameters have been matched, the weapon will have the greatest probability of striking the target.

In actual deliveries, however, the parameters are frequently not matched exactly. This is understandable considering that the controls available to the pilot (throttle and elevator control) do not directly, instantaneously or independently control the position or

initial velocity vector. Furthermore, dive angle information is not directly available from any aircraft instrument and the information which is directly available (true airspeed and altitude) must be mentally processed by the pilot before he can physically react , thereby adding further delay. Finally, the aircraft itself cannot react instantaneously to control inputs. Gauthier [1] has shown that sudden perturbations of the angle of attack caused by pilot induced changes in pitch attitude (elevator control) will cause the information provided by a fixed gunsight to be unreliable for several seconds. In addition , as shown in Fig 2, the gunsight image is constantly moving across the earth so that the proper sight 'picture' occurs precisely once during the dive.



NOTE: *Although Depression from flight path (106 mils) extracted from the ballistic tables is corrected for parallax, the remaining calculations ignore these factors. Therefore it is apparent that there are small geometric anomalies in the above diagram.*

Fig 2 SIGHT LINE MOTION IN A DIVE

In spite of these difficulties, there are strategies which help the pilot to learn a solution to the problem. First, the deliveries have been standardized so that the pilot may concentrate his efforts at mastering several basic maneuvers. This practice tends to reduce the magnitude of delivery errors. The second aspect which aids the pilot is known as error analysis. Since actual conditions rarely match those of the practice patterns, the pilot is taught to recognize those errors which are present and to apply corrective measures. Fig 3 graphically depicts the effect of various errors in airspeed, dive angle, release altitude, and aim point. For each of the standard deliveries, there is a table in reference [2] which lists, for each weapon, the effect upon weapon impact of errors of 10 knots in true airspeed (fast and slow), one degree in dive angle (steep and shallow), 100 feet in release altitude(high and low), and one milliradian in sight setting (plus and minus).

To use the tables, the pilot memorizes key values for the weapons he is going to release. During the tracking portion of his dive, he first attempts to minimize the errors in each of the delivery parameters. If he decides that the value of some or all of the delivery parameters will not equal the preselected values, he estimates the cumulative effect of all such errors on weapon impact. Having estimated this miss distance, he then deliberately causes another error either in release altitude or sight angle to counteract the effect of the previous errors.

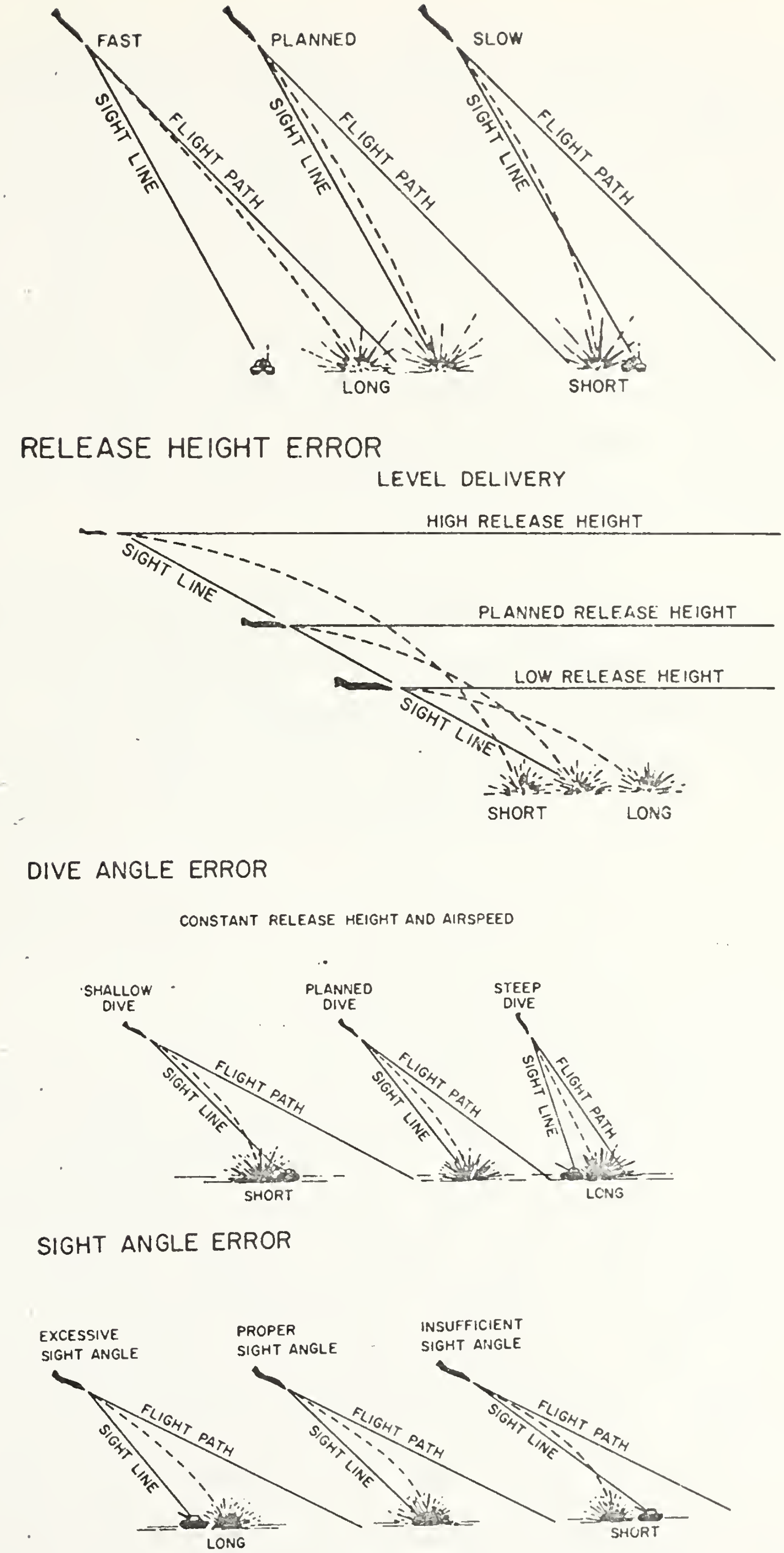


Fig 3 EFFECTS OF AIRSPEED, HEIGHT, DIVE, AND SIGHT ERRORS

As an illustration of this method, suppose the pilot estimates that he will be 10 knots fast and one degree steep at release altitude and that the combined effect of the errors will place the weapon 100 feet past the target. If, in the error sensitivities chart for the particular weapon, the entries for +100 ft. and -1 mil are -25 feet and -10 feet respectively, then the pilot may choose to release the weapon 400 feet high in relation to the preselected release altitude or he may use an imaginary sight line which represents an angle of 10 mils less than the preselected angle.

In view of the difficulties involved in fixed sight dive bombing, it is not surprising that considerable effort has been devoted to the development and implementation of computer systems to improve the delivery accuracy of all current generation Naval Attack aircraft.

D. AIR TO AIR GUNNERY

In air-to-air gunnery, the pilot of a fixed sight aircraft essentially solves his aiming problem in the same manner as for air to ground weapons delivery. He selects several representative situations and consults a table to determine the correct sight setting for each particular situation. In air to air gunnery, however, the pilot would usually like to be able to fire his aircraft's guns at any time he has a good chance of hitting the target. Therefore, rather than try to match any preselected set of firing conditions, the pilot takes the best guess and fires. The guns are loaded with a mixture of tracer rounds so that the pilot visually adjusts his aim depending on his evaluation of the effect of previous aim angles.

III. PROPOSED SOLUTION

In order to achieve the full benefit of the low cost of the micro computer, it was assumed that no additional sensor equipment such as doppler, air-to-ground ranging devices, or inertial navigation devices would be included in the modified system. Instead, the system would be designed around existing components with ultimate responsibility for problem solution still resting with the pilot. The micro computer is used chiefly to perform those calculations which the pilot of fixed sight aircraft now estimates.

A. COMPONENTS

The components of the modified system are depicted in Fig 4. Their relationship to the overall system is given below.

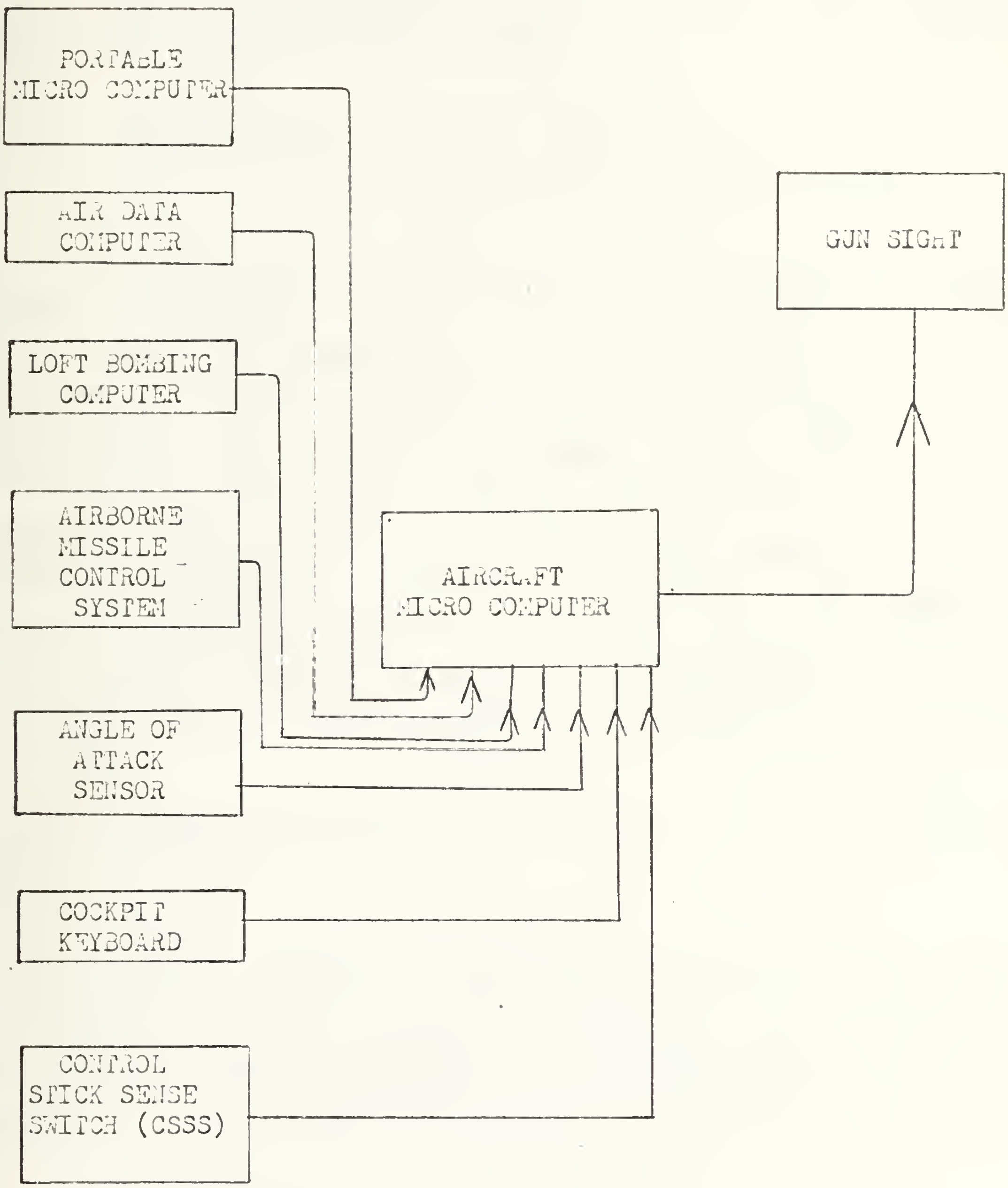


Fig 4 SYSTEM COMPONENTS

1. <u>Control Stick Sense Switch</u>

An on/off switch which is activated 'on' when the pilot begins tracking the target.

2. <u>Portable Micro Computer With Auxiliary Memory</u>

A device whose auxiliary storage contains a complete library of standard release parameters and error sensitivity factors for each weapon authorized for carriage and release from the particular aircraft. Each weapon would require approximately 128 bytes of storage. It is assumed that no more than 50 such weapons would apply to any particular aircraft. The ground based micro computer would be capable of retrieving blocks of such data and passing the data to the micro computer aboard the aircraft. It is also assumed that no more than three different weapons would be carried by a particular aircraft on any flight.

3. <u>Air Data Computer</u>

A device currently installed on Naval aircraft which provides analog signals corresponding to true airspeed, calibrated airspeed, and altitude. These signals would be converted to digital format to be read by the micro computer.

4. <u>Loft Bombing Computer</u>

An attitude reference gyro of the type currently installed in the F-4 whose analog signals corresponding to

pitch and roll angle as well as rate of pitch and heading change would be converted to digital format to be read by the micro computer.

5. Cockpit Keyboard

Any standard numerical keyboard, of the type used on pocket calculators, which has at least five function switches and light emitting diodes to confirm register contents. This device would be used by the pilot, or preferrably by a crewman, to input the mode (air-to-air or air-to-ground), and if in the air-to-ground mode to input the desired delivery, weapon to be released, target elevation, and aircraft gross weight.

6. Micro Computer

A micro computer with a word size of at least eight bits and speed at least that of the INTEL 8080 (2.5 micro second instruction cycle).

7. Gunsight

Either a standard fixed gunsight modified by replacing the fixed reticle light source with an array of addressable light emitting diodes, or a standard 'heads up' gunsight.

8. Airborne Missile Control System

One of the several models of air-to-air radars currently installed on the F-4 which provides analog signals

corresponding to the present range to the target and the rate of closure. These analog signals would be converted to digital format to be read by the micro computer.

9. Angle of Attack Sensor

A device which is currently installed on Navy jet aircraft which provides an analog signal corresponding to the angle between the flight path of the aircraft and the FUSELAGE REFERENCE LINE. This signal would be converted to digital format for use in air-to-air calculations.

B. DESCRIPTION OF USE

Fig 5 shows the overall timing sequence for the functions of the system.

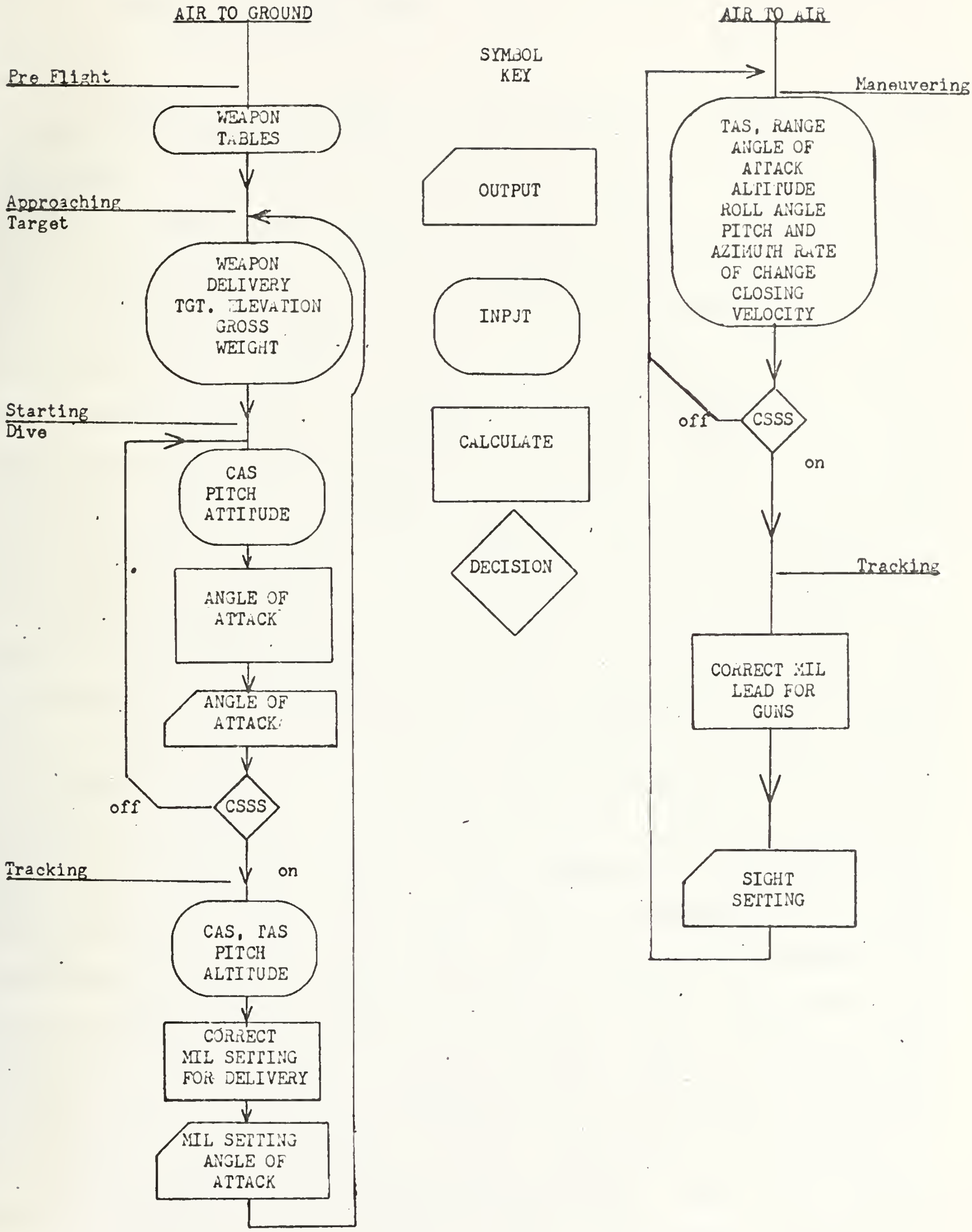


Fig 5 TIME DIAGRAM

1. Air to Ground Mode

Prior to flight, the aircraft is loaded with some authorized ordnance configuration. After the aircraft is operating on internal electrical power, a portable micro computer loads the appropriate tables into the memory of the aircraft's computer. As the aircraft approaches the target, the pilot/crewman keys a standard delivery and weapon code into the micro computer along with the target elevation and aircraft gross weight. As the pilot commences his roll-in, the micro computer samples calibrated airspeed and pitch angle and calculates the angle of attack of the fuselage reference line for a steady state dive at that pitch angle and calibrated airspeed and displays the angle of attack in mils on the gunsight. The pilot uses this information to establish the aircraft in a dive path which intersects the earth at some predetermined distance beyond the target (aim off point). When the aircraft is established in the proper dive, the pilot actuates the control stick sense switch and the computer begins to sample true airspeed, calibrated airspeed, altitude, and pitch angle. The pilot makes no further throttle adjustments. The computer calculates dive angle and estimates what the release parameters (airspeed and dive angle) will be when the aircraft reaches the prescribed release height above the earth. This sampling and calculation takes about two seconds. The computer then calculates the effect of any errors in the estimated airspeed and dive angle and corrects for the impact error by addressing a new diode in the gunsight or sending a correction signal to the heads up gunsight. The new sight setting would be calculated using the error sensitivity factors which had been read prior to flight. The pilot uses the corrected sight setting as the new aiming reference and places the revised sight pipper over the target at release

altitude and manually releases the weapon. After dive recovery, the computer is reset and the process is repeated as desired.

2. Air to Air Mode

For air to air use, there would be no need to load tables into the aircraft computer prior to flight. Instead, the program and appropriate tables would remain in the computer memory.

In flight the pilot/crewman would select the air-to-air mode. The computer would then begin to sample true airspeed, altitude, present range to the target, closure rate, roll angle and pitch and azimuth rates of change.

At this time the 35 mil setting would be illuminated on the gunsight. When the pilot had established a suitable tracking position with the sight held steady on the target, he would activate the control stick sense switch.

The computer would then calculate the proper lead angle for the most recently sampled conditions and display this lead angle on the gunsight. The pilot would adjust to the new aim angle as smoothly and quickly as possible and fire the guns. Tracers would still be mixed with other ammunition so that the pilot could adjust his fire as necessary. The time required to perform the calculations would be about .2 seconds.

IV. ANALYSIS AND TEST

A. AIR TC GROUND

1. General Considerations

If it is assumed that density, temperature, and the speed of sound are continuous, differentiable functions of altitude, then there exist unique solutions of equations (7) and (8) for each set of initial conditions. Moreover, it is intuitively clear that if the solutions were written in the component form

$$x(t)=F(v_x^0,v_y^0,x^0,y^0,t) \quad (9)$$

and

$$y(t)=H(v_x^0,v_y^0,x^0,y^0,t), \quad (10)$$

then the position of the weapon at time t could be considered to be a continuous function of the initial conditions. That is, for any neighborhood, N, of a point $(x(t),y(t))$ which represents the position of the weapon at time, t, after release (with initial conditions

$(v_x^0, v_y^0, x^0, y^0))$, there exists a neighborhood, U, of the initial conditions such that any identical weapon released with initial conditions which were in U would, at time, t, be in N. Furthermore, it may be assumed that first partial derivatives of F and H exist within U so that

$$dX = F_{v_x} * dV_x^0 + F_{v_y} * dV_y^0 + F_x * dX^0 + F_y * dY^0 \quad (11)$$

and

$$dY = H_{v_x} * dV_x^0 + H_{v_y} * dV_y^0 + H_x * dX^0 + H_y * dY^0. \quad (12)$$

Where the variables and partials on the right represent changes in the initial conditions and those on the left represent position at some time, t, which is held constant .

Since the proposed system incorporates no additional sensor devices, it must perform essentially the same type of calculations which the pilot of a fixed sight aircraft now performs. It samples airspeed, altitude, and pitch attitude and predicts what the value of true airspeed and dive angle will be at release altitude. These values are then compared with the standard release parameters for the particular delivery being used. Any difference between the predicted value and the desired value is converted to a gunsight correction which must be applied to the sight to counteract the effect of the release airspeed or dive angle error. The sum of the correction for airspeed and the correction for dive angle is then applied to the gunsight and the pilot flies the aircraft to place the new sight image over the target at release altitude.

Since the proposed solution relies on the error sensitivity tables, and since these tables are based on the

partial derivative of F with respect to several of the components of the initial condition (for example, an error in true airspeed changes v_x, v_y, and x), and since the solution assumes that effects of changes in airspeed, dive angle, and aim angle are linear and independent, an analytical proof of the validity of these assumptions would require an explicit representation of F and H. Unfortunately, there is no known closed form solution available to cover all the possible sets of initial conditions. Therefore, a series of computer experiments were performed to determine whether the method of error sensitivity analysis was suitable.

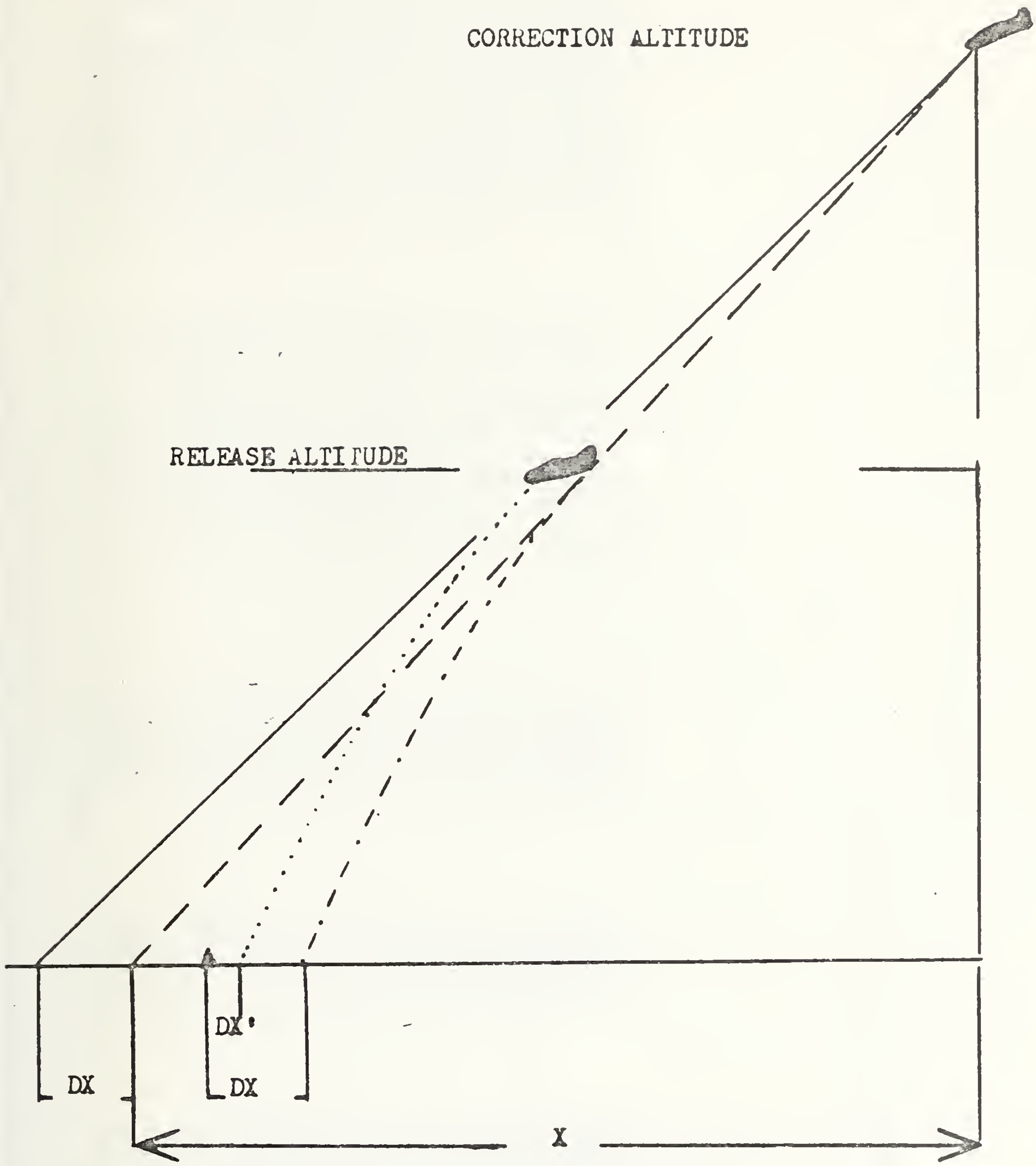
2. Tests of the Proposed Solution

a. Static Accuracy

The first test of the proposed solution was designed to measure the effectiveness of the error analysis technique. To separate the error analysis technique from any errors which might be induced by airspeed prediction or dive angle calculation, it was assumed that these functions were performed exactly by the micro computer. To measure the ability of the system to improve accuracy, an arbitrary value of plus 200 feet or minus 200 feet was assigned to the uncorrected impact error, DX in figure 6. The original dive angle was assigned a value which was five degrees steep or five degrees shallow. It was assumed that the correction which was applied to the gunsight would cause the bomb to hit the target if the pilot could establish a parallel dive path whose displacement from the original dive path was -DX feet (measured along the X axis). It was assumed that, instead of performing such a maneuver, the pilot used the

new sight image to make a single change in his dive path. This change occurred three seconds prior to reaching release altitude and moved the aim off point -DX feet. This maneuver causes a small change in the dive angle for which the gunsight was not compensated. At release altitude, the effect of this change in dive angle was computed using the error sensitivity tables for the Mk-76 Practice Bomb (DX' figure 6).

A FORTRAN program was executed to determine the values of DX', based on the previous assumptions. The program is listed in Appendix C and results are in Table 1. In general the release error sensitivity method improved accuracy by a factor of eight, and, in the worst case, by a factor of five.



DIVE BEFORE CORRECTING

DIVE AFTER CORRECTING

UNCORRECTED BOMB

CORRECTED BOMB

Fig 6 SIGHT ANGLE CORRECTION IN A DIVE

DESIRED DIVE	ACTUAL DIVE	DX	CORRECTION ALT	DTHET	DX'
10.00000	5.00000	-200.0	1396.18	-0.6158447E-01	-0.4926758E 01
10.00000	5.00000	200.0	1396.18	0.6312180E-01	0.3850430E 01
10.00000	15.00000	-200.0	1396.18	-0.5307684E 00	-0.4246147E 02
10.00000	15.00000	200.0	1396.18	0.5702133E 00	0.3478300E 02
20.00000	15.00000	-200.0	2280.32	-0.3293943E 00	-0.1087001E 02
20.00000	15.00000	200.0	2280.32	0.3441753E 00	0.9292734E 01
20.00000	25.00000	-200.0	2280.32	-0.8682861E 00	-0.2865344E 02
20.00000	25.00000	200.0	2280.32	0.9286804E 00	0.2507437E 02
30.00000	25.00000	-200.0	4140.75	-0.4852905E 00	-0.1601459E 02
30.00000	25.00000	200.0	4140.75	0.5035858E 00	0.1460399E 02
30.00000	35.00000	-200.0	4140.75	-0.8901672E 00	-0.2937552E 02
30.00000	35.00000	200.0	4140.75	0.9315186E 00	0.2701404E 02
30.00000	25.00000	-200.0	5140.75	-0.3922729E 00	-0.1882910E 02
30.00000	25.00000	200.0	5140.75	0.4041443E 00	0.1737820E 02
30.00000	35.00000	-200.0	5140.75	-0.7201385E 00	-0.3456665E 02
30.00000	35.00000	200.0	5140.75	0.7469635E 00	0.3211943E 02
45.00000	40.00000	-200.0	5613.26	-0.8288727E 00	-0.1740633E 02
45.00000	40.00000	200.0	5613.26	0.8584900E 00	0.1631131E 02
45.00000	50.00000	-200.0	5613.26	-0.1177155E 01	-0.2472025E 02
45.00000	50.00000	200.0	5613.26	0.1219147E 01	0.2316379E 02
60.00000	55.00000	-200.0	8975.84	-0.8477325E 00	-0.2288878E 02
60.00000	55.00000	200.0	8975.84	0.8656311E 00	0.2164076E 02
60.00000	65.00000	-200.0	8975.84	-0.1039673E 01	-0.2807117E 02
60.00000	65.00000	200.0	8975.84	0.1057510E 01	0.2643776E 02

TABLE 1 SIMULATION OF DTHET AND DX'

b. Real Time Accuracy

An important part of the proposed solution was the calculation of the angle of attack of the fuselage reference line. The pilot would use this information to establish the aircraft in a straight path which intersected the ground at a precomputed distance beyond the target, called the aim off point, reference[3]. The computer would also use this angle of attack information to compute the actual dive angle of the aircraft.

Although all Naval carrier based jet aircraft are equipped with angle of attack sensors, these devices are designed primarily to provide accurate information in the landing phase of flight and are inherently inaccurate during high speed low angle of attack situations, reference[4].

Therefore, in order to have a more accurate value for the angle of attack, figure 2-56 of reference[2] was used as a source, Fig 7.

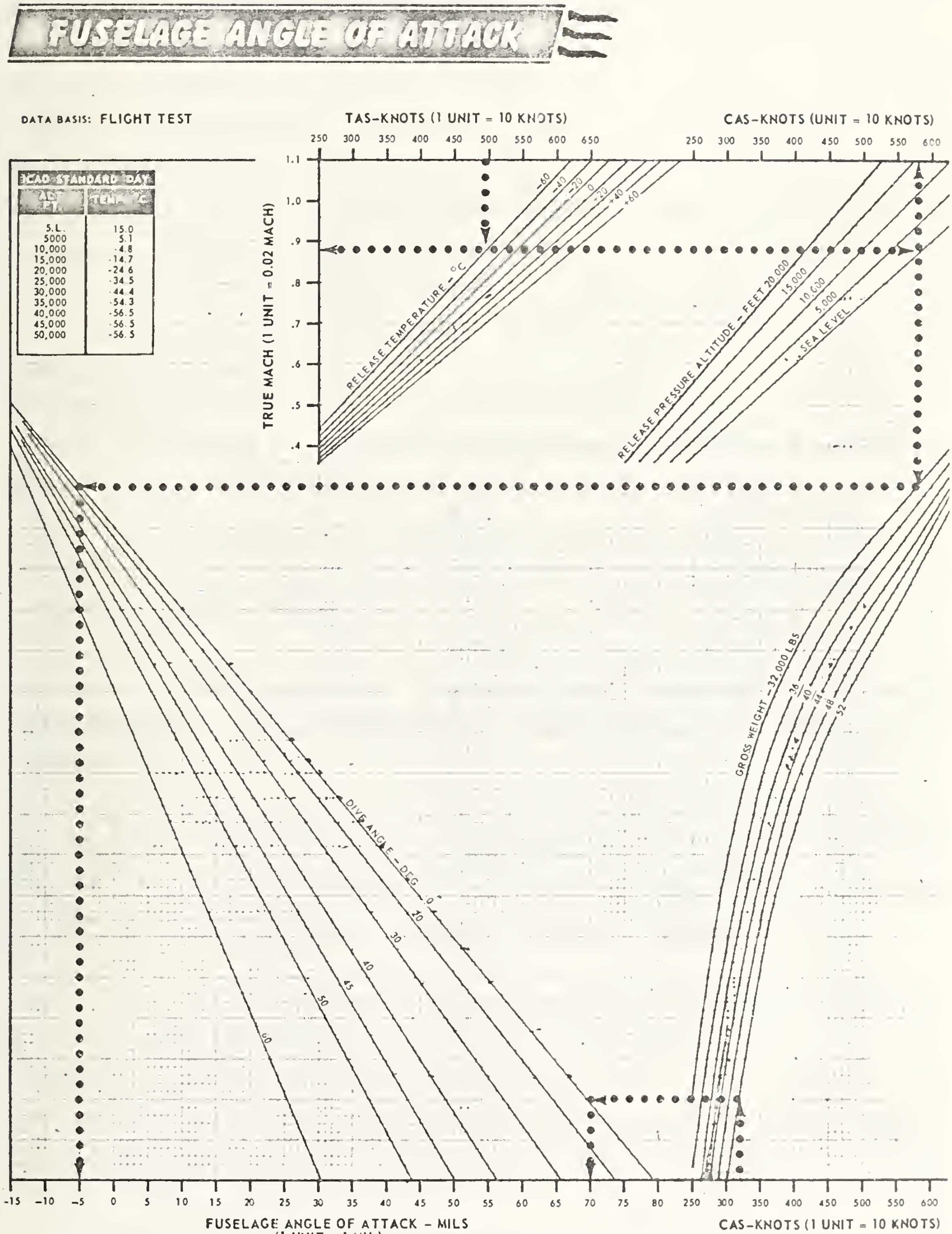


Fig 7 ANGLE OF ATTACK CHART

Figure 7 is the chart which a pilot would use to calculate the angle of attack for any particular air to ground delivery condition. The chart may be used with either of two sets of input keys. The first set is dive angle, temperature, true airspeed, and gross weight. The second set consists of calibrated airspeed, gross weight, and dive angle. Since the central air data computer provides calibrated airspeed information, the second set was used. To calculate manually the angle of attack for a given calibrated airspeed, gross weight, and dive angle the following procedure is used:

(1) Find the desired calibrated airspeed (cas) on the right half of the bottom of the chart.

(2) Move vertically to the curve labeled with the appropriate weight.

(3) Proceed horizontally to the left until intersecting the straight line labeled by the desired dive angle.

(4) Proceed directly down the chart and read the desired value of the angle of attack in mils from the bottom of the chart.

To reproduce the information contained in figure 7, it was necessary to represent the weight curves and straight lines in an algebraic form. The form chosen was the polynomial. Since all air-to-ground charts are based on the assumption that the aircraft gross weight is 42,000 pounds with scalar adjustments for different weights, the same scheme was adopted for the micro computer system. The 42,000 pound curve was approximated with a second degree interpolating polynomial, F(cas). The straight lines were

considered to be of the form

y=m * x + b

where 'y' represents ordinate values, 'x' represents abscissa values, 'm' is the slope of the line, and 'b' is the 'y' intercept value. Substituting ALPHA, the angle of attack, for 'x', F(cas) for 'y', m(THETA) for m, and B(THETA) for 'b', the following equation was evaluated:

ALPHA=(F(cas)-B(THETA))/m(THETA).

F was a quadratic interpolation of the 42,000 pound curve. The argument of F, cas, was taken as the difference between calibrated airspeed and 295. This linear translation allowed single byte multiplication to be used. THETA was the dive angle. B was a tabled, first divided difference function of the zero mil intercept values of the straight lines in the lower left quadrant of figure 7. M, the slope of these straight lines, was found to approximate closely the value of '-SECANT(THETA)'.

Therefore, in order to speed the calculations, the equation which was actually solved was

mil=cos(THETA)*(B(THETA)-F(cas)). (13)

The COSINE calculation was based on a divided difference table which was arranged in four degree increments.

An ALGOL program was executed to simulate an INTEL 8080 fixed point arithmetic evaluation of the preceeding equation. A listing of the program is contained in Appendix C. The results of the ALGOL simulation appear in table 2. A FLM version of the routine was timed by the INTERP8 as requiring 4798 micro seconds.

AIRSPEED CAS	300	320	340	360	380	400	420	440	460	480	500	520
DIVE DEGREE												
10	61	51	43	36	31	26	21	18	16	15	15	16
20	59	49	42	35	30	25	20	17	15	15	15	15
30	51	43	36	30	26	21	17	15	13	13	13	13
40	48	40	34	29	24	20	16	14	13	12	12	13
50	34	29	24	20	17	14	11	10	9	8	8	9
60	31	26	22	18	15	13	10	9	8	7	7	8

TABLE 2. COMPUTED FUSELAGE REFERENCE LINE ANGLE OF ATTACK

c. Forecasting Accuracy

A third topic for investigation is the ability of the micro computer to forecast accurately the value of the release true airspeed early in the dive. The basic forecasting scheme is to fit a parabola through a series of samples of airspeed and altitude . It is assumed that both values can be read to the equivalent of four decimal places of precision. In fitting the parabola, altitude is treated as the independent variable and the release true airspeed is assumed to be

$$airspeed = C_1 + C_2 * relalt + C_3 * relalt^2 \quad (15)$$

where 'relalt' is the calculated release altitude.

To determine whether such a method was appropriate, it was necessary to first construct a model of the F-4 in a dive, and then write a computer program to simulate the model. The model chosen was that of Newton's second law of motion:

F=m*a

where force, F, was assumed to be

Thrust + W*sin(THETA)-drag.

Thrust and drag were opposing forces acting parallel to the flight path, THETA was constant, and thrust, mass, and weight, W, were also constant.

The resulting differential equations were

A=(Thrust + W * SIN(THETA) - drag)/mass (16)

and

$V=A*t.$ (17)

Drag was assumed to be a function of dive angle and true airspeed. Figure 2-61 of reference [2] was selected as the source of data from which to obtain values of drag. This particular figure represents true airspeed vs. altitude at various dive angles for a particular engine speed, gross weight, and external configuration (drag index 60). The relationship is represented by a series of smooth curves, where each curve corresponds to a particular dive angle. The curves themselves were first represented using an interpolating second degree polynomial determined by a least squares fit of eight evenly spaced sets of data points. The coefficients of the polynomial were calculated by the Naval Postgraduate School Computer Library subroutine LSQPL2. With these coefficients, it was then possible to determine for any altitude and dive angle a true airspeed value based on the curves.

Using the relationship previously established, it was possible to determine an approximate value for the time required to fly from one altitude to another. Using increments of 10 knots and assuming that the rate of change of velocity was linear within the interval, an empirical approximation for the accelleration in a particular time increment was calculated. The value of the drag during that time increment could then be calculated. This method was used to establish pairs of data points (true airspeed, drag) for each of the dive angles given. An additional pair (0,0) was added for each dive and the resulting data was again fitted using the routine LSQPL2. The coefficients were used in FORTRAN subroutine DRAG, see Appendix E.

With the drag function computed, equations (16) and (17) were numerically solved using a standard

Runge-Kutta fourth order integration scheme. this was done in a FORTRAN subroutine, INTEG, (see Appendix E).

Using the model, three forecasting schemes were tested. The first scheme consisted of sampling airspeed and altitude values at one second intervals. A Newton divided difference interpolating polynomial was then generated and release true airspeed was predicted as

$$tas_{release} = tas_{t_0} + (\text{release alt}-alt_{t_0})*(F_{(0,1)} + (\text{release alt}-alt_{t_1})*F_{(0,1,2)}). \quad (18)$$

$F_{(0,1)}=(F_0-F_1)/(x_0-x_1)$,

$F_{(1,2)}$ is analagously defined,

$F_{(0,1,2)}=(F_{(0,1)}-F_{(1,2)})/(x_0-x_2)$,

X represents the independent variable and F represents the dependent variable.

The second method consisted of taking a total of twelve samples during a two second period. The first four samples were added and the average was taken as the true value. Similar averages were used to represent the two remaining inputs to a Newton divided difference second degree interpolating polynomial of the type described above.

The third prediction scheme was to take 20 samples during the same interval and to generate a least squares orthogonal polynomial to fit the data. The polynomial was also a parabola and it was generated and evaluated based on subroutines contained in reference [5].

For the experiment, 1000 dive runs were simulated. Each run was based on the following assumptions:

(1) Entry airspeed equals 345 knots.

(2) Thrust equals 20,000 pounds.

(3) Dive angle equals 30^{0}.

(4) Entry altitude equals 6000 feet.

(5) True airspeed and altitude would be read to four decimal digits of precision.

(6) On any particular run, the altitude and airspeed error would remain constant. Between runs the error would be normally distributed with the mean airspeed error of zero and standard deviation of .5 knot. The altitude error would have a mean of zero and a standard deviation of 10 feet.

The latter distributions are the result of assuming that the errors were normally distributed with the maximum allowable error equal to three times the standard deviation. Allowable instrument errors were obtained from reference [6].

Normal distributions were simulated using the Naval Postgraduate School Computer Library package LLRANDOM. The test was repeated with a different seed to verify original results. See Appendicies A and E.

d. System Performance

To determine whether the use of the micro computer would significantly improve the delivery accuracy of the F-4 in the air to ground enviornment, an experiment was conducted based on the following assumptions:

(1) The previously described model represented an F-4 in a dive bombing run.

(2) The Mk-81 Low Drag Bomb is a typical unguided air to ground weapon.

(3) In the simulation, it would be assumed that the pilot, at release altitude, would have the sight aimed at the target.

(4) All weapons would be released from a position 7 feet below and 18 feet aft of the gunsight.

(5) All deliveries would be in no-wind conditions.

(6) The path of the Mk-81 Low Drag Bomb could be described by the following set of equations which were obtained from reference [7]:

$$X'' = -E * X' \quad (19)$$

and

$$Y'' = -E * Y' - g \quad (20)$$

where X represents down range travel, Y represents altitude, X', and Y' are the horizontal and vertical components of the velocity vector. The value of the other variables was determined as follows:

$$E=(c * p * V_a * K_d)/144$$

where

c is the reciprocal ballistic coefficient (diameter^2 / weight),

p is the air density $0.0751366 * e^{-(0.00003158 *Y)}$,

V_a is the true airspeed in ft/sec^2.,

and

K_d is the drag coefficient.

The experiment consisted of simulating 1000 dive runs for each of the following standard deliveries:

20^0 dive, 2000 ft. release, 450 knots true airspeed

30^0 dive, 3000 ft. release, 450 knot true airspeed

30^0 dive, 5000 ft. release, 500 knot true airspeed

45^0 dive, 4000 ft. release, 450 knot true airspeed

45^0 dive, 6000 ft. release, 500 knot true airspeed

60^0 dive, 7000 ft. release, 500 knot true airspeed.

On each run the sampling method previously described as one second interval sampling was used. The predicted airspeed was calculated by equation (18). The entry conditions were considered to be normally distributed

about a correct set of (airspeed, altitude, thrust, and dive angle) which was calculated to achieve the desired delivery parameters. The standard deviations of the distributions of the entry conditions were 10 knots for true airspeed, 200 feet for altitude, 2.5^0 for dive angle, and 750 pounds for thrust.

Normal distributions were simulated using the Naval Postgraduate School subroutine LLRANDOM. The standard deviations were assigned with a data statement. Two pseudorandom variables, x and y, were obtained from the LLRANDOM package. The variable x was obtained from a uniform (0,1) distribution and y was obtained from a normal (0,1) distribution. The desired value, z, was then calculated as

> z= DMEAN + y * STDV * COIN(x) where DMEAN is the desired mean, STDV is the standard deviation, and COIN is a statement function which returns a +1 if x<.5 and a -1 otherwise.

After the release conditions had been predicted by the subroutine SAMP, two conditions were simulated. First, that the aircraft had no micro computer and that the pilot continued in a steady dive to release altitude. Second, that the pilot had a micro computer, that the micro computer supplied his gunsight with a corrected sight setting equal to the value calculated by SAMP , and that the pilot adjusted his aircraft's dive path as soon as this information was available , so that at release altitude, the new sight setting was 'on' the target.

For each condition, a simulated bomb was dropped at release altitude. A miss for the bomb was calculated as the distance between the point where the sight angle

intersected the earth and the down range travel, x, which was numerically computed (based on the equations (19) and (20)). In addition, in the case of the modified flight path, a correct sight setting was also calculated. Finally, the ratio of the miss distance with the micro computer to the miss distance without the micro computer was calculated. If the micro computer gave a greater miss than the basic aircraft, the ratio was set to plus or minus 1.1, depending on whether the errors were both on the same side of the target.

Arrays were built with these 1000 values and histograms were printed showing the distribution of the various values. See appendix B. The FORTRAN routine which simulated the experiment is in appendix F. An additional table was constructed from the histograms which compares the median miss distance under the assumptions that the micro computer was or was not used. See table 3.

RELEASE PARAMETERS			RANGE ERROR PROBABLE*	
DIVE	ALTITUDE	AIRSPEED	UNCORRECTED	CORRECTED
20	2000	450	88	44
30	3000	450	68	16
30	5000	500	120	20
45	4000	450	70	28
45	6000	500	139	53
60	7000	500	60	32

* Range error probable is the distance from the target of the median bomb.

TABLE 3. Mk 81 BOMB DROP SIMULATION

e. Micro Computer Suitability

The previously tested error sensitivity algorithm was converted from FORTRAN to PLM for test on the INTEL 8080. The program was compiled on the Naval Postgraduate School IBM 360/65 and interpreted using the INTERP8 subroutine. Timing data was obtained and found to be .75 seconds for the entire program. See Appendix G. The program was then executed on the INTEL 8080 and final output (sight setting) was found to be in agreement with sample results which had been obtained from executing the FORTRAN version on an SDS 9300 computer.

B. AIR TO AIR

1. General

In air-to-air gunnery considerations, it must be assumed that the position of the target is some function of time,

$$(x,y,z) = F(a(t), b(t), c(t)).$$

Since, in general, no assumptions can be made to restrict this motion relative to the (x,y,z) coordinate system of air to ground considerations, a new coordinate system is introduced. The origin of the new system, (x',y',z') is the muzzle of the fighter aircraft's cannon. The x' axis is always oriented so that a bullet's initial velocity vector will be aligned with the positive x' axis. The y' axis is perpendicular to the x' axis and forms, with

the x' axis, a plane which contains the wing roots of the fighter. The z' axis is orthogonal to the (x',y') plane with the positive direction measured in the same direction as the vertical tail of the fighter.

It should be noted that the x' axis is not always aligned with the gun barrel boresight line. This is caused by the bullet's velocity vector being the vector sum of the basic muzzle velocity vector and the aircraft velocity vector. When the aircraft is flying at an angle of attack greater than zero these two vectors are not coincident. Therefore, the x' axis is shifted away from the gun boresight line toward the relative wind.

The set of points from which a fighter can effectively employ guns against an airborne target lies within a 30 degree cone emanating from the tail of the target. The minimum firing range within this cone is approximately 500 feet and the maximum range is approximately 2000 feet.

The dimensions of this firing region effectively restrict the problem so that, for a bullet to hit the target, the time of flight is less than two seconds. This short time of flight, together with the basic muzzle velocity of the standard aircraft cannon (3300 fps), allow the computations of the proper lead angle to be performed in four distinct steps, Reference [8]. The steps are as follows:

(1) Estimate the future angular displacement of the target from the present line of sight. This displacement is assumed to be caused by the target's present velocity vector acting as a constant during the time of flight of the bullet. This angle is called the lead for target motion.

(2) Calculate the effect of gravity drop.

(3) Calculate the effect of the fighter's angle of attack.

(4) Calculate the effect of the distance between the gun and the gunsight (parallax).

2. Lead for Target Motion

The calculation of the lead for target motion in a plane parallel to the (y',z') plane is based on the following analysis of the situation:

(1) If the fighter is tracking the target, that is, the fighter is in the firing cone with the 35 mil pipper held steady on the target, the relative positions of the two aircraft are 'close' to the positions needed for successful gun firing.

(2) Therefore, assume that the sight line and the x' axis are coincident.

(3) At this time, the fighter's velocity minus the rate of closure represents the target's velocity component parallel to the x' axis.

(4) The rate at which the fighter is turning, in radians/second, multiplied by the range is a close approximation to the target's velocity component parallel to the (y',z') plane.

(5) If there exists a time, t', such that a bullet fired at time t=0 will strike the target at time t',

then the geometry of the flight of the bullet in a plane containing the x' axis and the component of the velocity vector of the target which is in the plane parallel to the (y',z') plane, can be approximated by Fig 8.

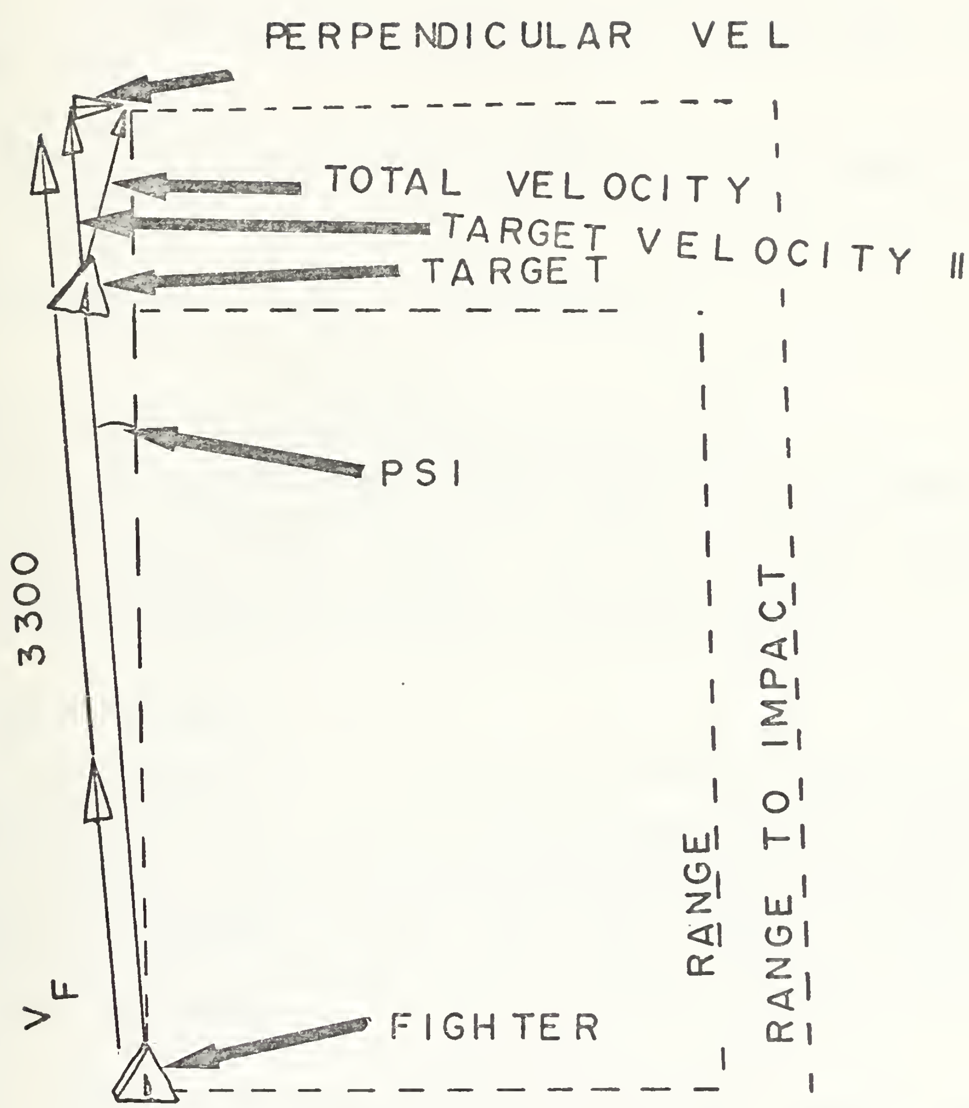


Fig 8 AIR TO AIR GUNNERY DIAGRAM

(6) Therefore, the lead for target motion orthogonal to the x' axis can be approximated by the angle, psi, (see Fig 8).

The calculation of the angle in mils uses the fact that

$$\lim_{x \to 0} \sin(x)/x = 1.$$ This implies that, for small angles,

$$\mathrm{ARCSIN}(x/y) \doteq x/y \doteq \mathrm{ARCTAN}(x/y)$$

where $\doteq$ means "is approximately equal to".
In fact, for angles smaller than 200 mils, the maximum error of these approximations is 4 mils. Since the set of possible answers lies within the range 0-200 mils, the following equation was solved to determine psi.

psi= VO/VX'.
VO, the component of the target's velocity vector which was orthogonal to the X' axis, was calculated as the product of the fighter's rate of turn multiplied by the range to the target, multiplied by 1000. VX', the average velocity of the bullet, was calculated as the range to impact divided by the time of flight.

Since the calculation, at this stage, ignores gravity, and since the bullet otherwise satisfies the assumptions of the air to ground weapon , provided that the x' axis is parallel to the surface of the earth, equation (19) can be modified to give

$$A_{x'} = -E * V_{x'} \quad (21).$$

Since the velocity of the bullet during its time of flight will be several times larger than the speed of sound, and since the shape of the K_d vs. Mach curve is almost flat above 1.6 times the speed of sound, equation (21) can be further simplified to

$$A_{x'} = -p * K * V_{x'}^2 \quad (22)$$

or equivalently, since $V_{x'} > 0$,

$$A_{x'} / V_{x'}^2 = -p * K.$$

Since the effect of gravity is ignored, the density, p, will remain constant so that (22) becomes

$$A_{x'} / V_{x'}^2 = -K_2, \text{ a constant.} \quad (23)$$

Integrating both sides with respect to t gives

$$-1/V_{x'} = -K_2 * t + C_1. \quad (24)$$

Solving (24) for the initial conditions of the bullet as it leaves the gun gives

$$1/V_{x'} = (K_2 * V_m * t + 1)/V_m \quad (25)$$

where V_m was taken to be $3300 + V_f$, and V_f was the fighter's velocity in feet per second. Expressing (25) in an equivalent form yields

$$V_{x'} = V_m / (K_2 * V_m * t + 1). \quad (26)$$

Integrating equation (26) again with respect to t gives the equation for distance traveled by the bullet

$$x' = \ln(K_2 * V_m * t + 1)/K_2 + C_3. \quad (27)$$

Since x' at t=0 is zero, $C_3=0$.

The time of flight may now be calculated as the time, t_{tof}, when

$$RANGE + (V_f - V_c) * t_{tof} = \ln(K_2 * V_m * t_{tof} + 1)/K_2. \quad (28)$$

RANGE is the distance to the target at time t=0. V_c is the closing velocity at time t=0.

Since the argument of the natural logarithm in equation (28) is strictly greater than 1, a Newton's fixed point iteration function may be used to find the value of t_{tof}. The iteration function is

$$t_{n+1} = t_n - F(t_n)/F'(t_n). \quad (29)$$

F(t) and F'(t) were defined as follows:

$$F(t) = RANGE + (V_f - V_c) * t - \ln(V_m * K_2 * t + 1)/K_2 \quad (30)$$

and

$$F'(t) = (V_f - V_c) - V_m/(V_m * K_2 * t + 1). \quad (31)$$

The first approximation of t_{tof} was used to find the values VX', and subsequently psi. To reduce the time

required to calculate t_2, t_1 was always assigned the value one.

3. The Effect of Gravity Drop

In calculating the lead for target motion, the effect of gravity was ignored. A true trajectory, however, would always curve toward the earth as described by equation (20). For a time of flight less than two seconds, equation (20) may be simplified by assuming that E=0. This allows a closed form solution for the distance travelled by the bullet below the no gravity flight path during time, t_{tof}, seconds. The solution is

$$y = 32.17 * t^2/2 \qquad (32)$$

The error in (32) is less than 20 feet reference [8].

The angle, in milliradians, subtended by the distance y_{tof}, at a future range of x'_{tof} feet is

$$mils_{gravity\ drop} = y_{tof} * 1000/x'_{tof} \quad .$$

4. Effect of Angle of Attack

As the bullet leaves the barrel of the gun, it aligns with the relative wind. That is, the velocity vector of the bullet shifts from the gun boresight line to the x' axis. The amount of this shift, in mils, is calculated as

$$MILS_{AOA} = V_f * AOA/(V_f + 3300),$$

where AOA represents angle of attack, in mils, of the gun barrel boresight line.

5. Parallax Correction

Since the gun and the sight pivot are approximately seven feet apart in the z' direction, a small factor must be added to the sight setting. In the F-4, this setting is 3.19 mils, reference [8]. Fig 9 shows that the effect of adding a parallax correction is to have the zero sight line (ZSL) intersect the gun boresight line (TBL) at a known distance (harmonization range) in front of the fighter.

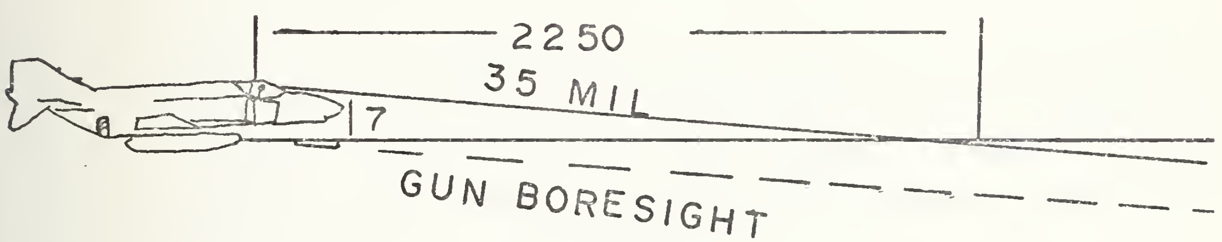


Fig 9 PARALLAX CORRECTION

6. Implementation and Timing

The calculations described above were coded into a PLM subroutine and tested on the INTERP8 simulation subroutine. The time of execution was found to be less than .2 seconds. In addition, a simulated sampling and data preparation routine was timed at approximately .15 seconds. See appendix H.

V. CONCLUSIONS

Based on the experiments performed and the timing data obtained, the micro computer is functionally capable of providing an improvement in air to ground delivery accuracy, which is on the order of a two fold increase in accuracy. Since the cost of micro computers in decreasing, whereas the cost of fuel and replacement aircraft is increasing, and since improved delivery accuracy means fewer sorties and aircraft exposed to hostile fire, a program to study the engineering factors and actual airborne effectiveness of the proposed micro computer modification is warranted.

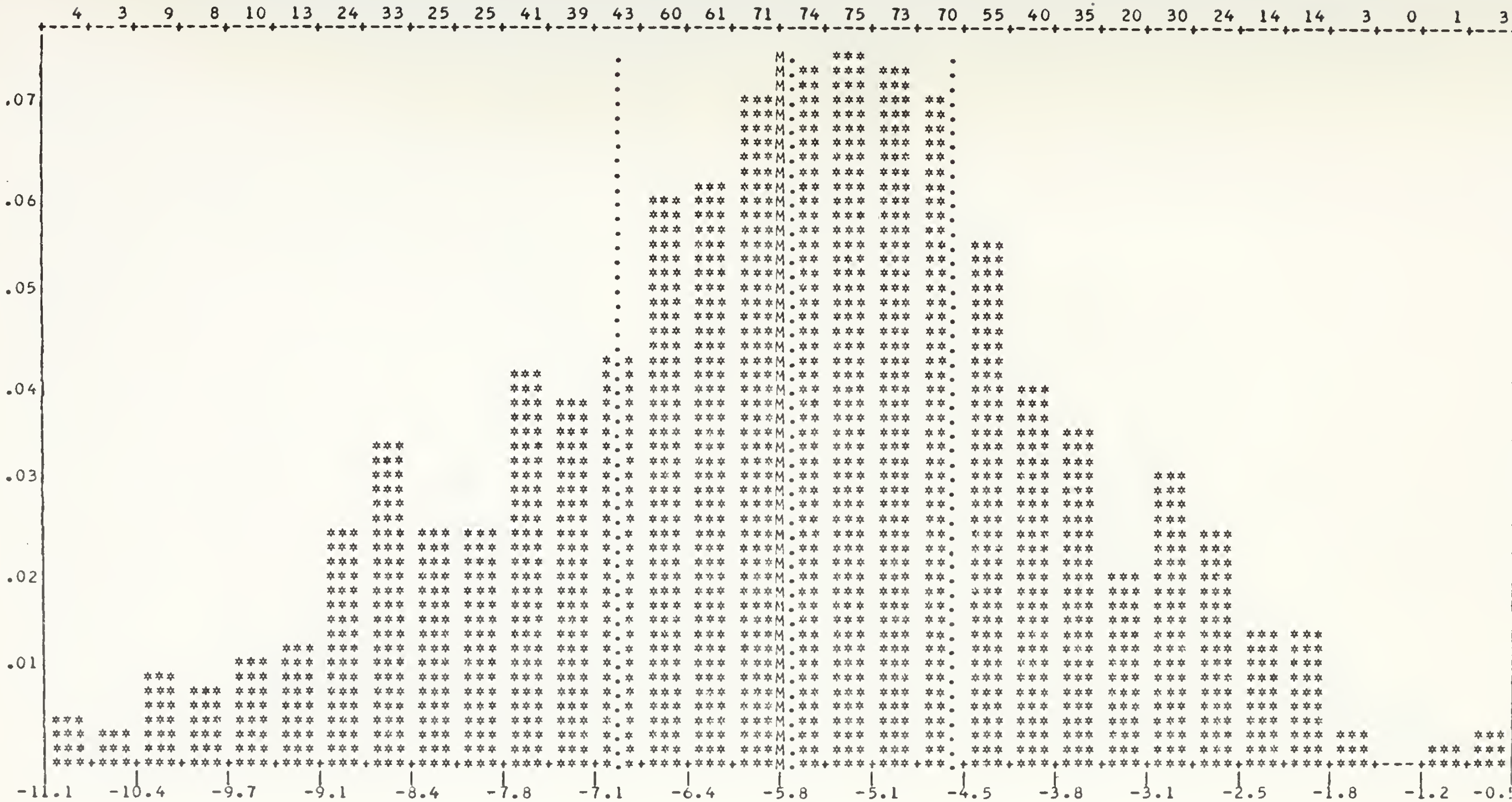
The air to air gunnery implementation was not compared to the fixed sight solution since there is no criteria by which to judge the accuracy of the pilot's guess in the latter case. The reaction time of the computer (less than .5 second) appears to be adequate.

Although no live tests were conducted on the system in either mode, such tests could be conducted at a relatively low cost by programming an A-6E or A-7E airborne computer to simulate the accuracy and timing of the proposed micro computer system. This would eliminate the need to reconfigure the hardware of the test aircraft, at least in the preliminary stages.

The cost of the micro computer and associated 10,006 bytes of memory necessary to execute the air to ground and air to air programs is one thousand one hundred and fifty dollars based on currently available prices. Overall, the

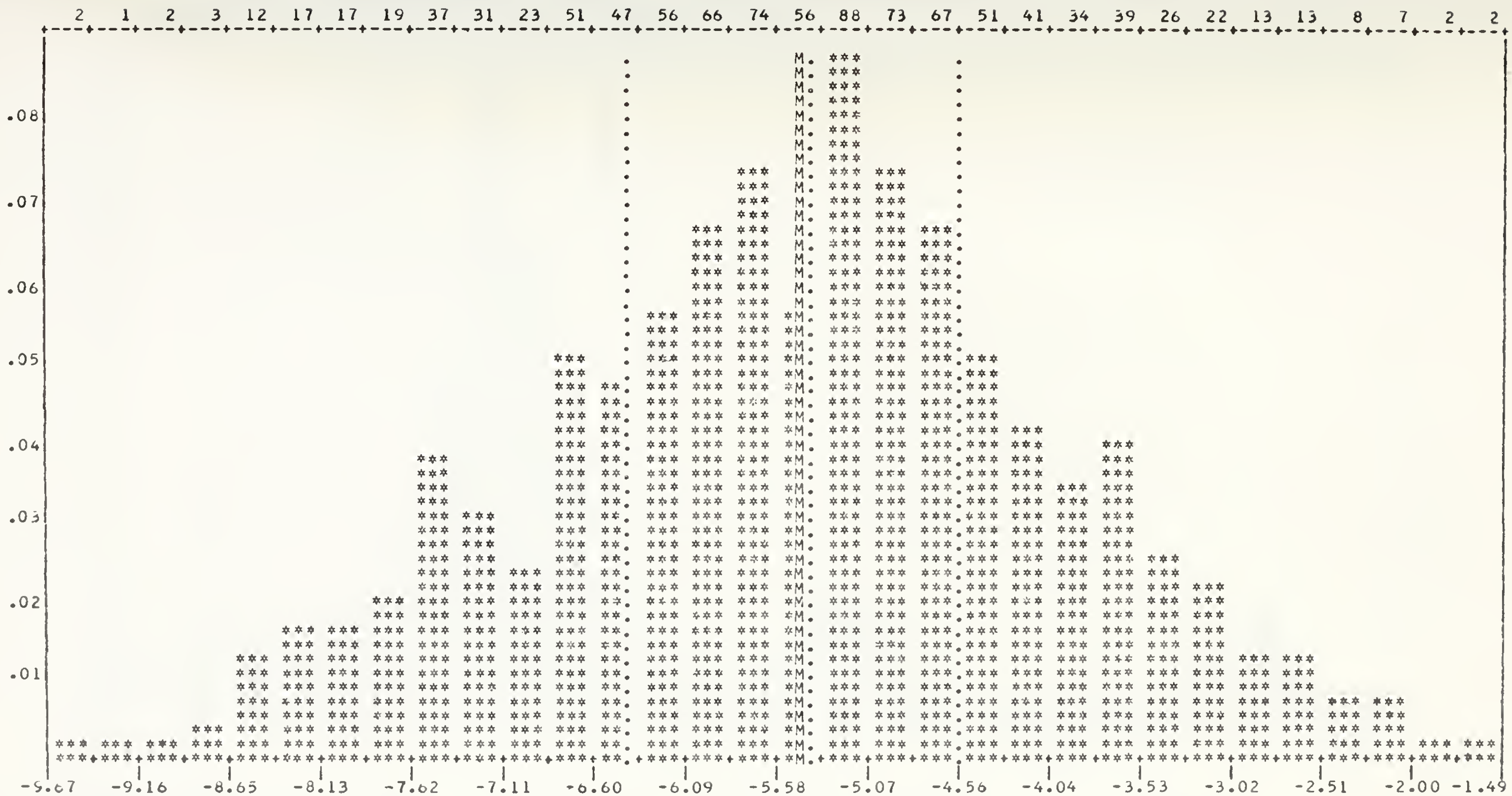
micro computer represents one way to help curb the rapid increase in the cost of aircraft procurement.

APPENDIX A



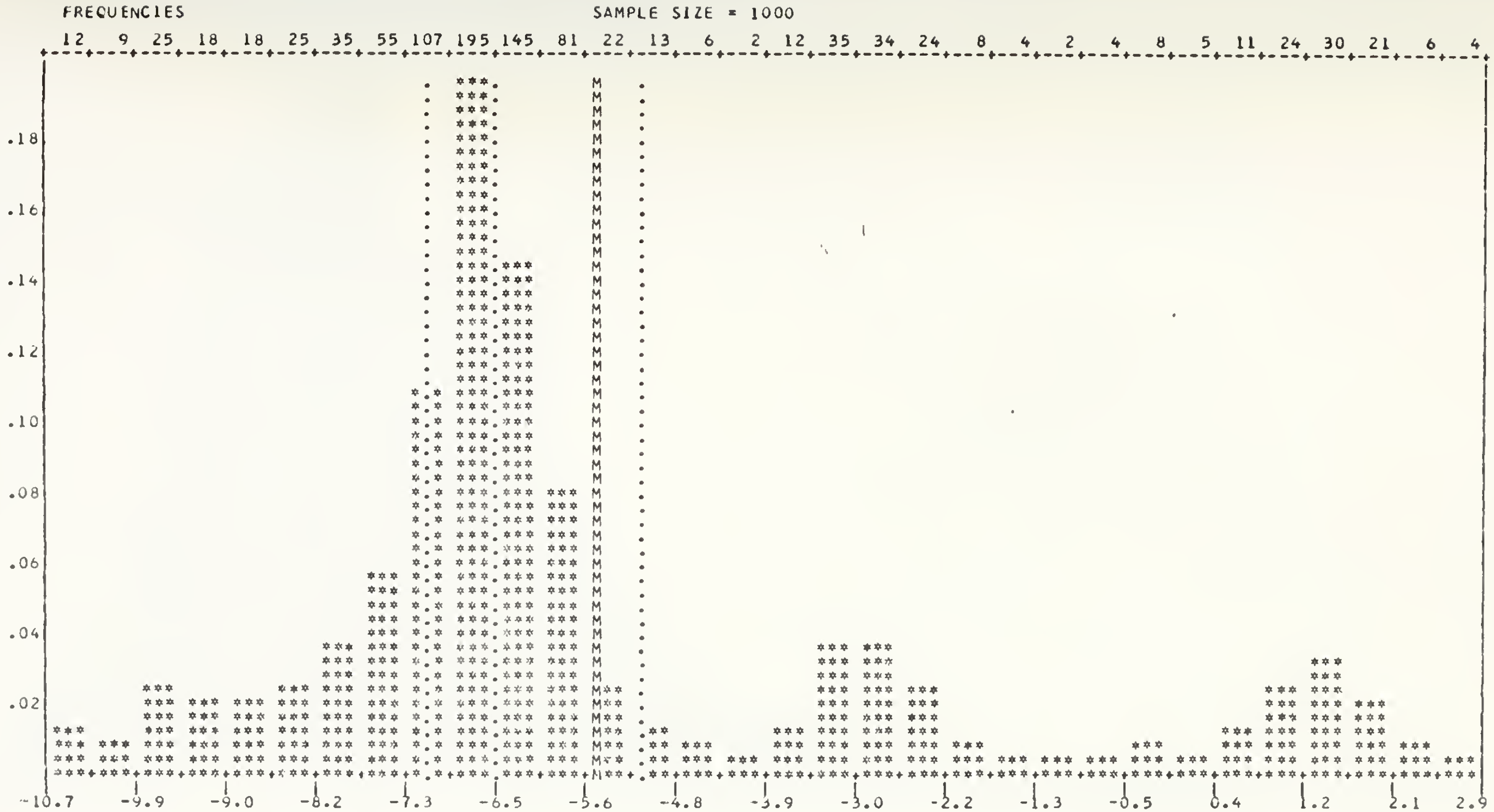
CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-5.771431E 00	VARIANCE	3.583900E 00	M3	-1.334822E 00	MINIMUM	-1.105664E 01
MEDIAN	-5.686279E 00	STD DEV	1.893119E 00	M4	3.584183E 01	.10 QUANTILE	-8.478027E 00
TRIMEAN	-5.710968E 00	COEF VAR	3.280155E-01	SKEWNESS	-1.967387E-01	.25 QUANTILE (HINGE)	-6.961426E 00
MIDMEAN	-5.678975E 00	MEAN DEV	1.502579E 00	KURTOSIS	-2.095242E-01	.50 QUANTILE (MEDIAN)	-5.686279E 00
MIDRANGE	-5.784058E 00	RANGE	1.054517E 01	BETA1	-1.330820E 00	.75 QUANTILE (HINGE)	-4.509888E 00
		MIDSPREAD	2.451538E 00	BETA2	3.577542E 01	.90 QUANTILE	-3.332031E 00
						MAXIMUM	-5.114746E-01

DISTRIBUTION OF ERRORS IN PREDICTED AIRSPEED USING ORTHOGONAL POLYNOMIAL



CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-5.454322E 00	VARIANCE	2.071266E 00	M3	-1.600868E-01	MINIMUM	-9.668701E 00
MEDIAN	-5.411377E 00	STD DEV	1.439190E 00	M4	1.166386E 01	.10 QUANTILE	-7.458740E 00
TRIMEAN	-5.434631E 00	COEF VAR	2.638623E-01	SKEWNESS	-5.370335E-02	.25 QUANTILE (HINGE)	-6.404297E 00
MIDMEAN	-5.429405E 00	MEAN DEV	1.153172E 00	KURTOSIS	-2.812433E-01	.50 QUANTILE (MEDIAN)	-5.411377E 00
MIDRANGE	-5.578491E 00	RANGE	8.180420E 00	BETA1	-1.596069E-01	.75 QUANTILE (HINGE)	-4.511475E 00
		MIDSPREAD	1.892822E 00	BETA2	1.164290E 01	.90 QUANTILE	-3.581543E 00
						MAXIMUM	-1.488281E 00

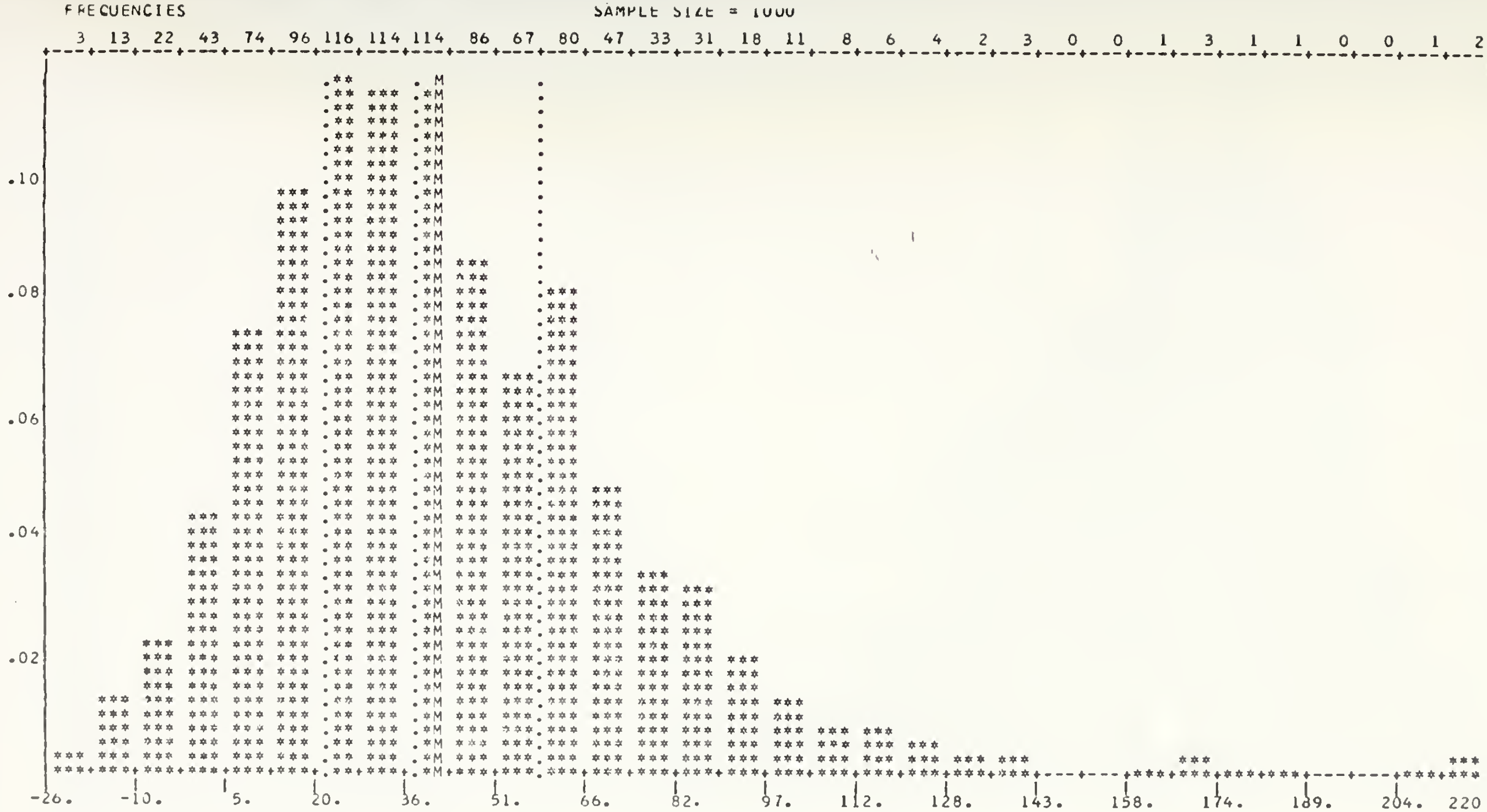
ERRORS IN PREDICTED AIRSPEED USING AVERAGED INPUT



CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-5.556598E 00	VARIANCE	8.707173E 00	M3	3.106447E 01	MINIMUM	-1.074634E 01
MEDIAN	-6.455444E 00	STD DEV	2.950792E 00	M4	2.896289E 02	.10 QUANTILE	-8.316406E 00
TRIMEAN	-6.288574E 00	COEF VAR	5.310430E-01	SKEWNESS	1.209061E 00	.25 QUANTILE (HINGE)	-7.130859E 00
MIDMEAN	-6.398429E 00	MEAN DEV	1.954018E 00	KURTOSIS	8.202124E-01	.50 QUANTILE (MEDIAN)	-6.455444E 00
MIDRANGE	-3.901733E 00	RANGE	1.368921E 01	BETA1	3.097134E 01	.75 QUANTILE (HINGE)	-5.112549E 00
		MIDSPREAD	2.018311E 00	BETA2	2.889246E 02	.90 QUANTILE	5.615234E-03
						MAXIMUM	2.942871E 00

ERRORS IN PREDICTED AIRSPEED USING ONE SECOND SAMPLES

APPENDIX B

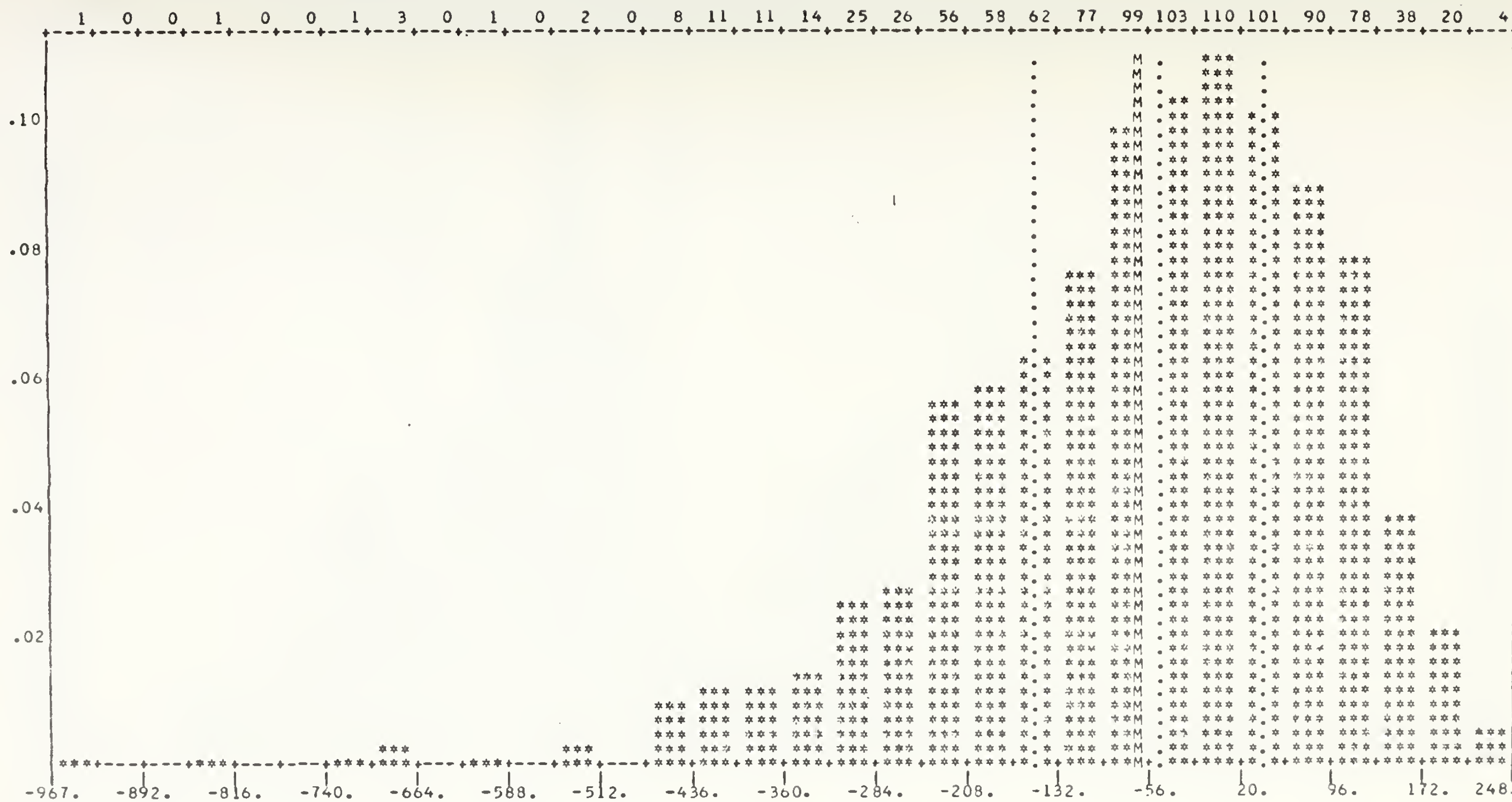


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	4.139508E 01	VARIANCE	9.699011E 02	M3	3.996695E 04	MINIMUM	-2.563037E 01
MEDIAN	3.704944E 01	STD DEV	3.114323E 01	M4	6.556798E 06	.10 QUANTILE	7.091309E 00
TRIMEAN	3.835812E 01	COEF VAR	7.523414E-01	SKEWNESS	1.323153E 00	.25 QUANTILE (HINGE)	2.035120E 01
MIDMEAN	3.754720E 01	MEAN DEV	2.314769E 01	KURTOSIS	3.970065E 00	.50 QUANTILE (MEDIAN)	3.704944E 01
MIDRANGE	9.710217E 01	RANGE	2.454651E 02	BETA1	3.984713E 04	.75 QUANTILE (HINGE)	5.898242E 01
		MIDSPREAD	3.863123E 01	BETA2	6.536207E 06	.90 QUANTILE	7.854053E 01
						MAXIMUM	2.198347E 02

ERROR IN DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
20.	450.	2000.

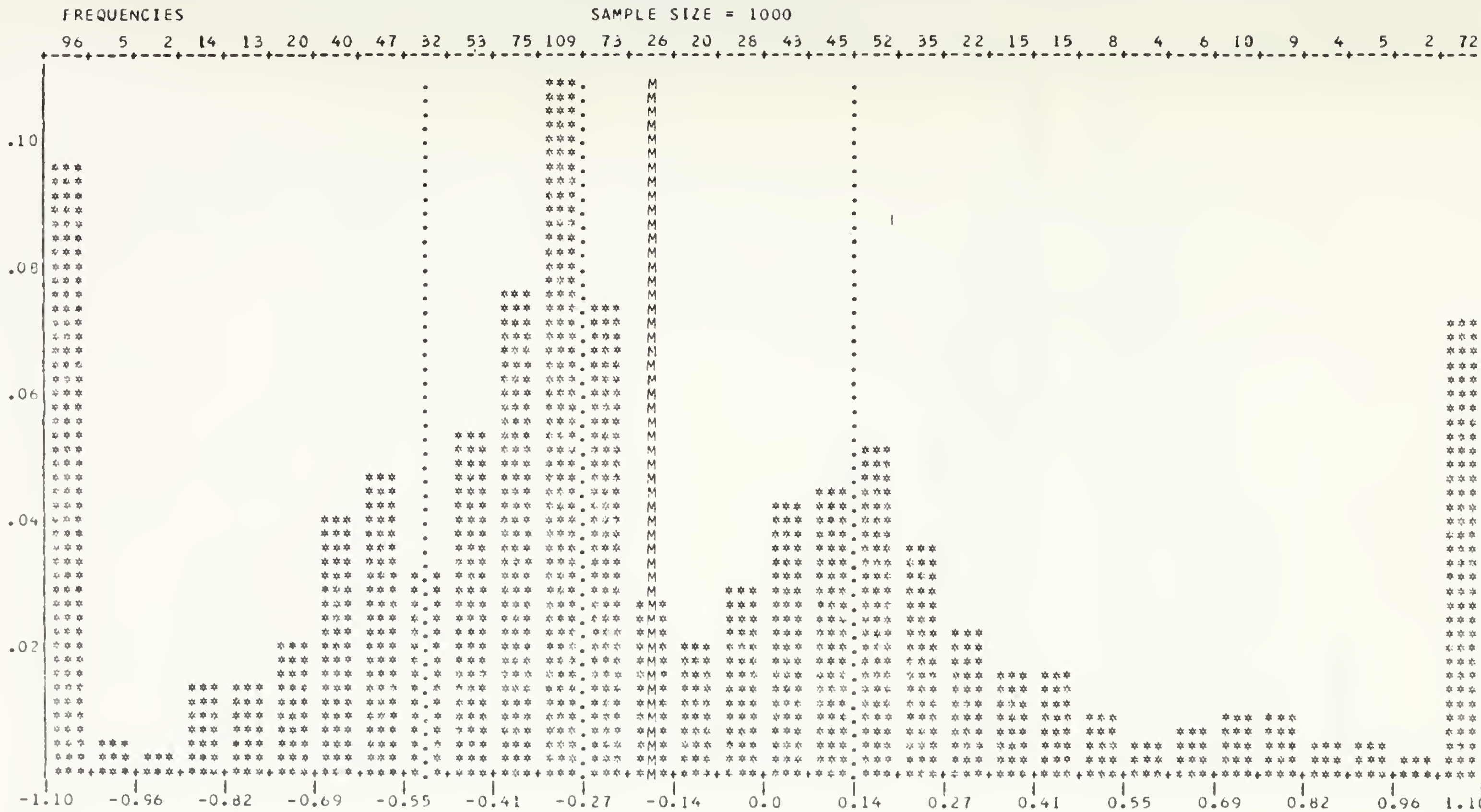


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-6.071706E 01	VARIANCE	2.326854E 04	M3	-3.694105E 06	MINIMUM	-9.674492E 02
MEDIAN	-4.264990E 01	STD DEV	1.525403E 02	M4	2.918793E 09	.10 QUANTILE	-2.490649E 02
TRIMEAN	-4.656146E 01	COEF VAR	2.512313E 00	SKEWNESS	-1.040771E 00	.25 QUANTILE (HINGE)	-1.497869E 02
MIDMEAN	-4.244736E 01	MEAN DEV	1.172591E 02	KURTOSIS	2.390946E 00	.50 QUANTILE (MEDIAN)	-4.264990E 01
MIDRANGE	-3.599658E 02	RANGE	1.214967E 03	BETA1	-3.683031E 06	.75 QUANTILE (HINGE)	4.884082E 01
		MIDSPREAD	1.986277E 02	BETA2	2.910361E 09	.90 QUANTILE	1.114954E 02
						MAXIMUM	2.475173E 02

ERROR IN UNCORRECTED DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
20.	450.	2000.

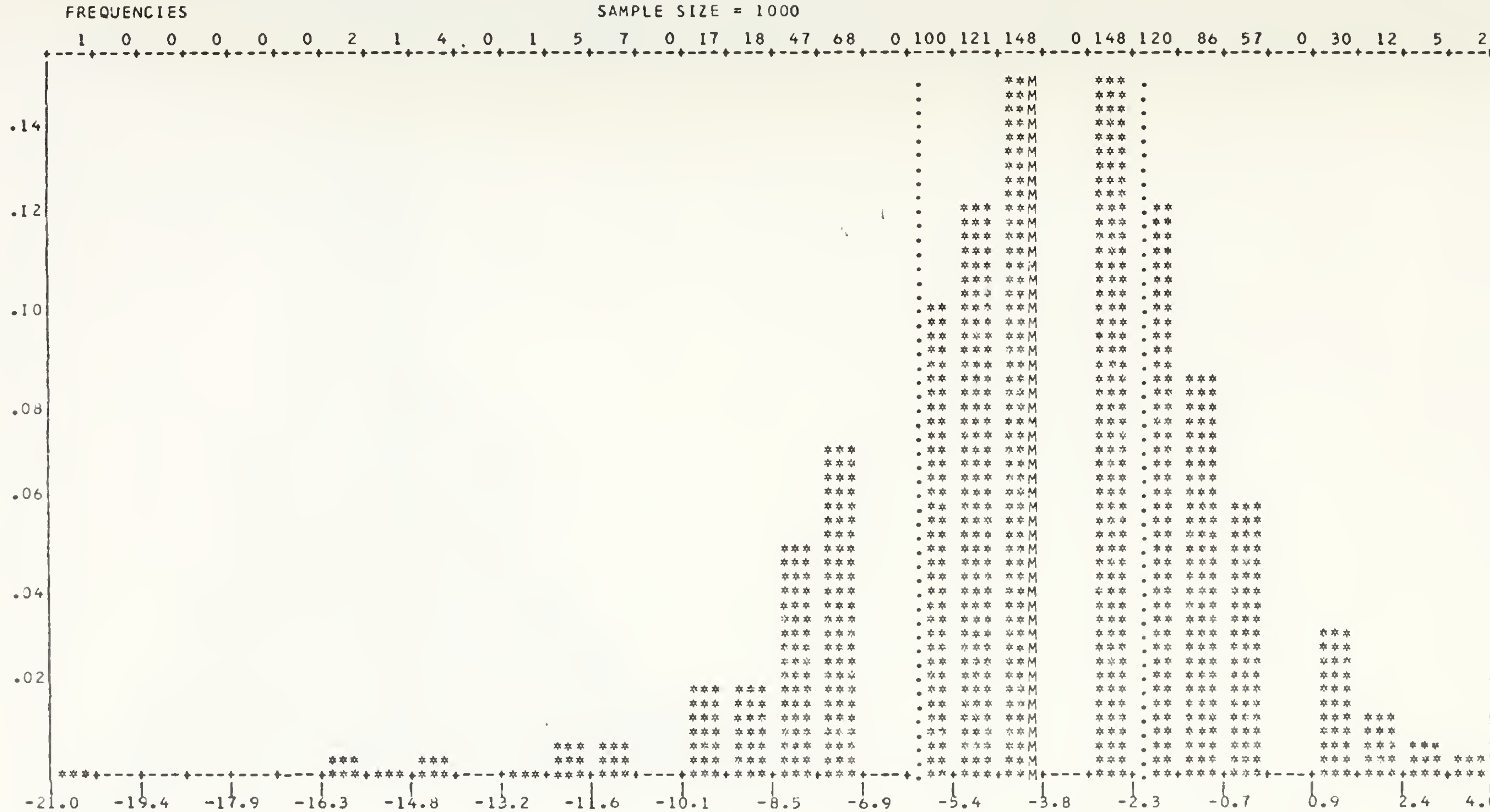


CENTRAL TENOENCY		SPREAO		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-1.729317E-01	VARIANCE	3.247562E-01	M3	9.854382E-02	MINIMUM	-1.099999E 00
MEDIAN	-2.774736E-01	STO DEV	5.698739E-01	M4	3.169917E-01	.10 QUANTILE	-9.689937E-01
TRIMEAN	-2.327664E-01	COEF VAR	3.295368E 00	SKEWNESS	5.324677E-01	.25 QUANTILE (HINGE)	-5.215559E-01
MIDMEAN	-2.250397E-01	MEAN DEV	4.319156E-01	KURTOSIS	5.613327E-03	.50 QUANTILE (MEOIAN)	-2.774736E-01
MIDRANGE	0.0	RANGE	2.199999E 00	BETA1	9.824842E-02	.75 QUANTILE (HINGE)	1.454371E-01
		MIDSPREAO	6.669930E-01	BETA2	3.163556E-01	.90 QUANTILE	6.698100E-01
						MAXIMUM	1.099999E 00

CORRECTED ERROR/UNCORRECTED ERROR

DESIREO DELIVERY

OIVE ANGLE	TRUE AIRSPEEO	RELEASE ALTITUDE
20.	450.	2000.

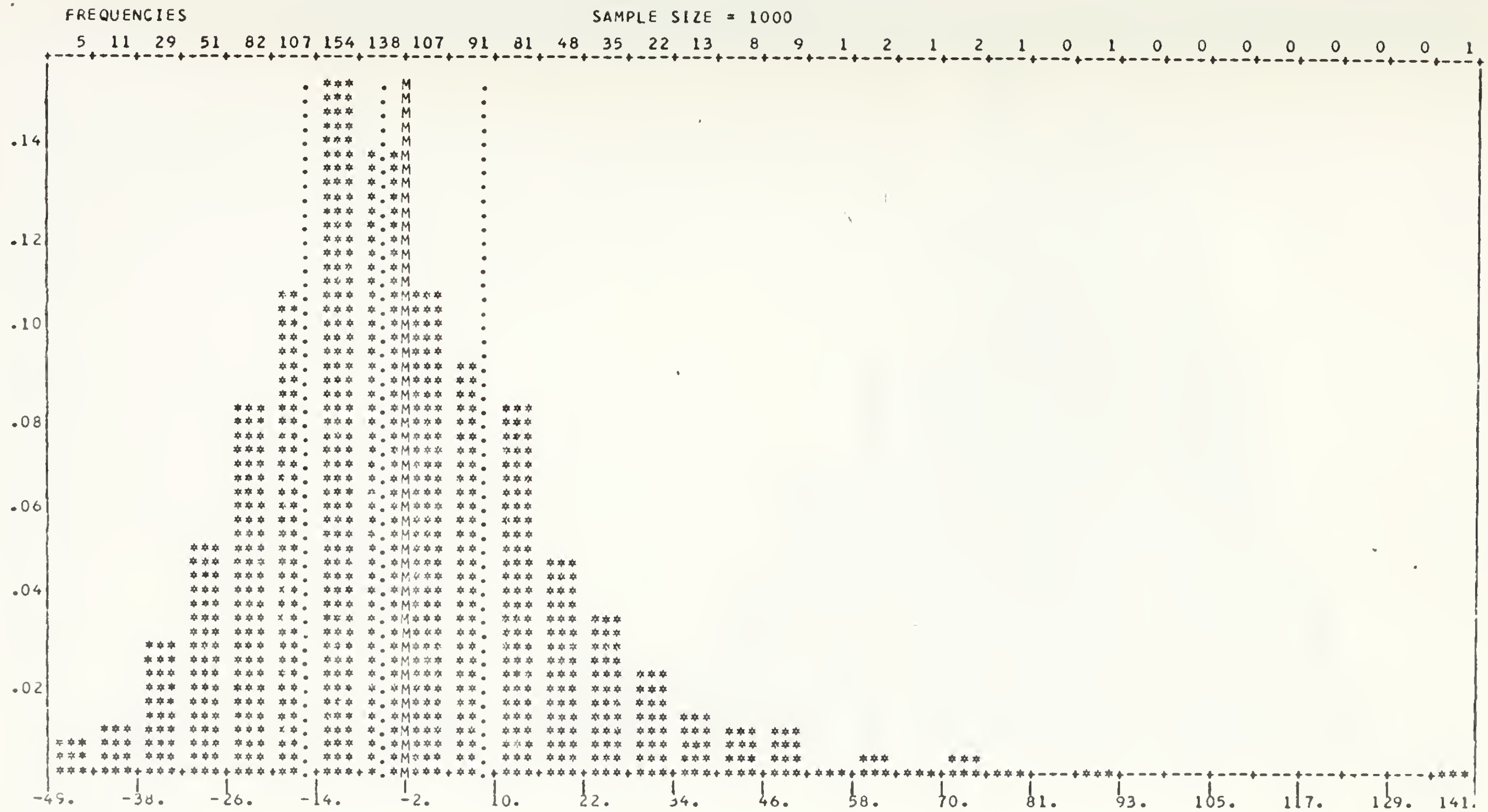


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-3.948000E 00	VARIANCE	8.663958E 00	M3	-1.631726E 01	MINIMUM	-2.100000E 01
MEDIAN	-4.000000E 00	STD DEV	2.943460E 00	M4	3.583765E 02	.10 QUANTILE	-8.000000E 00
TRIMEAN	-4.000000E 00	COEF VAR	7.455574E-01	SKEWNESS	-6.398420E-01	.25 QUANTILE (HINGE)	-6.000000E 00
MIDMEAN	-3.782000E 00	MEAN DEV	2.242000E 00	KURTOSIS	1.774269E 00	.50 QUANTILE (MEDIAN)	-4.000000E 00
MIDRANGE	-8.500000E 00	RANGE	2.500000E 01	BETA1	-1.626834E 01	.75 QUANTILE (HINGE)	-2.000000E 00
		MIDSPREAD	4.000000E 00	BETA2	3.573928E 02	.90 QUANTILE	0.0
						MAXIMUM	4.000000E 00

ERROR IN SIGHT SETTING

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
20.	450.	2000.

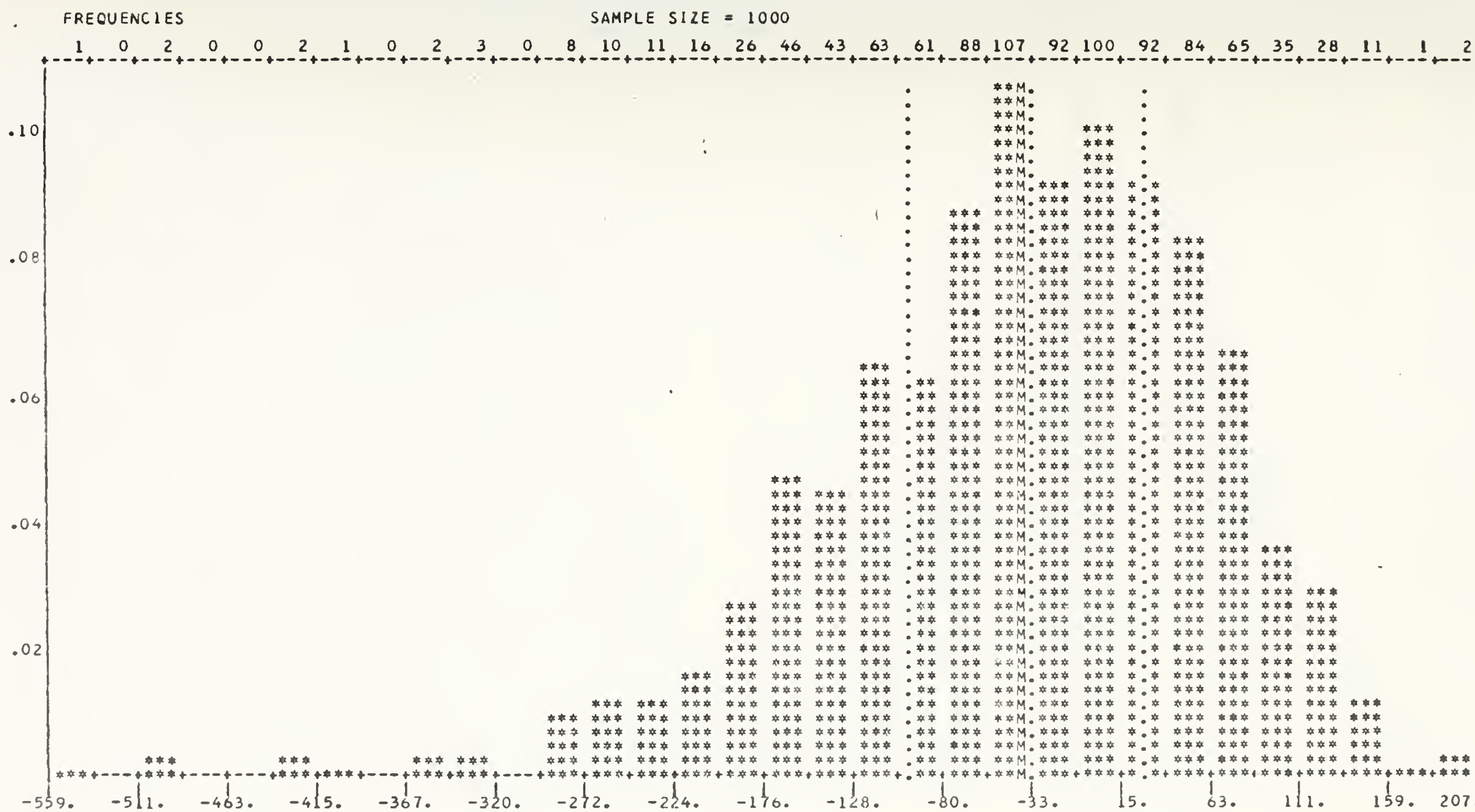


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-2.900000E 00	VARIANCE	3.787644E 02	M3	7.817664E 03	MINIMUM	-4.945020E 01
MEDIAN	-5.322998E 00	STD DEV	1.946187E 01	M4	9.827578E 05	.10 QUANTILE	-2.559155E 01
TRIMEAN	-4.525085E 00	COEF VAR	6.710989E 00	SKEWNESS	1.060532E 00	.25 QUANTILE (HINGE)	-1.560095E 01
MIDMEAN	-4.662196E 00	MEAN DEV	1.468108E 01	KURTOSIS	3.850279E 00	.50 QUANTILE (MEDIAN)	-5.322998E 00
MIDRANGE	4.575610E 01	RANGE	1.904126E 02	BETA1	7.794230E 03	.75 QUANTILE (HINGE)	8.146606E 00
		MIDSPREAD	2.374756E 01	BETA2	9.796861E 05	.90 QUANTILE	2.128906E 01
						MAXIMUM	1.409624E 02

ERROR IN DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
30.	450.	3000.

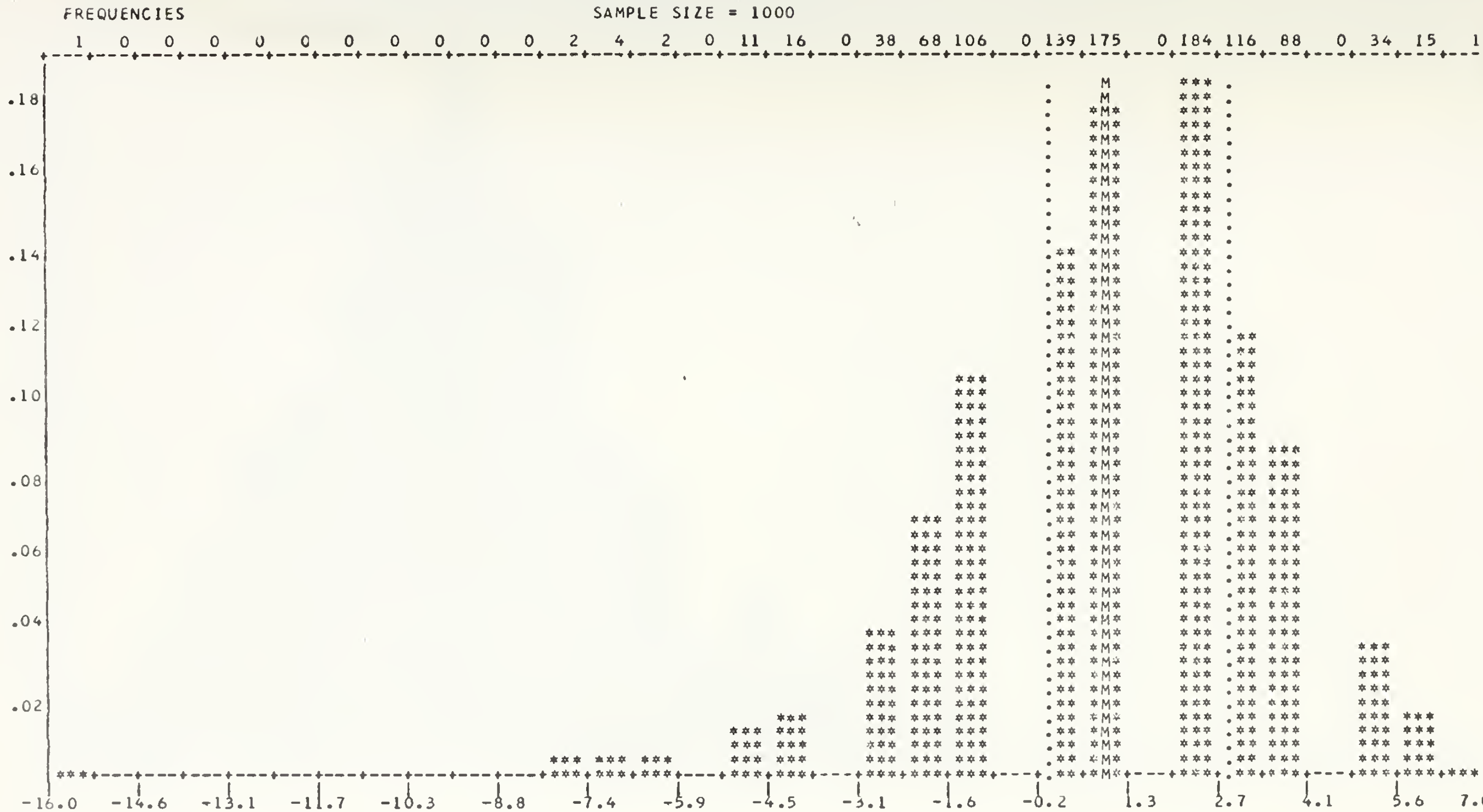


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-3.869339E 01	VARIANCE	9.899973E 03	M3	-8.074978E 05	MINIMUM	-5.586758E 02
MEDIAN	-2.950000E 01	STD DEV	9.949861E 01	M4	4.583593E 08	.10 QUANTILE	-1.667227E 02
TRIMEAN	-3.175598E 01	COEF VAR	2.571463E 00	SKEWNESS	-8.197668E-01	.25 QUANTILE (HINGE)	-9.924414E 01
MIDMEAN	-2.962051E 01	MEAN DEV	7.711867E 01	KURTOSIS	1.676684E 00	.50 QUANTILE (MEDIAN)	-2.950000E 01
MIDRANGE	-1.760673E 02	RANGE	7.652170E 02	BETA1	-8.050770E 05	.75 QUANTILE (HINGE)	3.122021E 01
		MIDSPREAD	1.304644E 02	BETA2	4.571131E 08	.90 QUANTILE	7.617529E 01
						MAXIMUM	2.065413E 02

ERROR IN UNCORRECTED DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
30.	450.	3000.



CENTRAL TENDENCY	
MEAN	9.630000E-01
MEDIAN	1.000000E 00
TRIMEAN	1.250000E 00
MIDMEAN	1.110000E 00
MIDRANGE	-4.500000E 00

SPREAD	
VARIANCE	5.783411E 00
STD DEV	2.404872E 00
COEF VAR	2.497271E 00
MEAN DEV	1.830999E 00
RANGE	2.300000E 01
MIDSPREAD	3.000000E 00

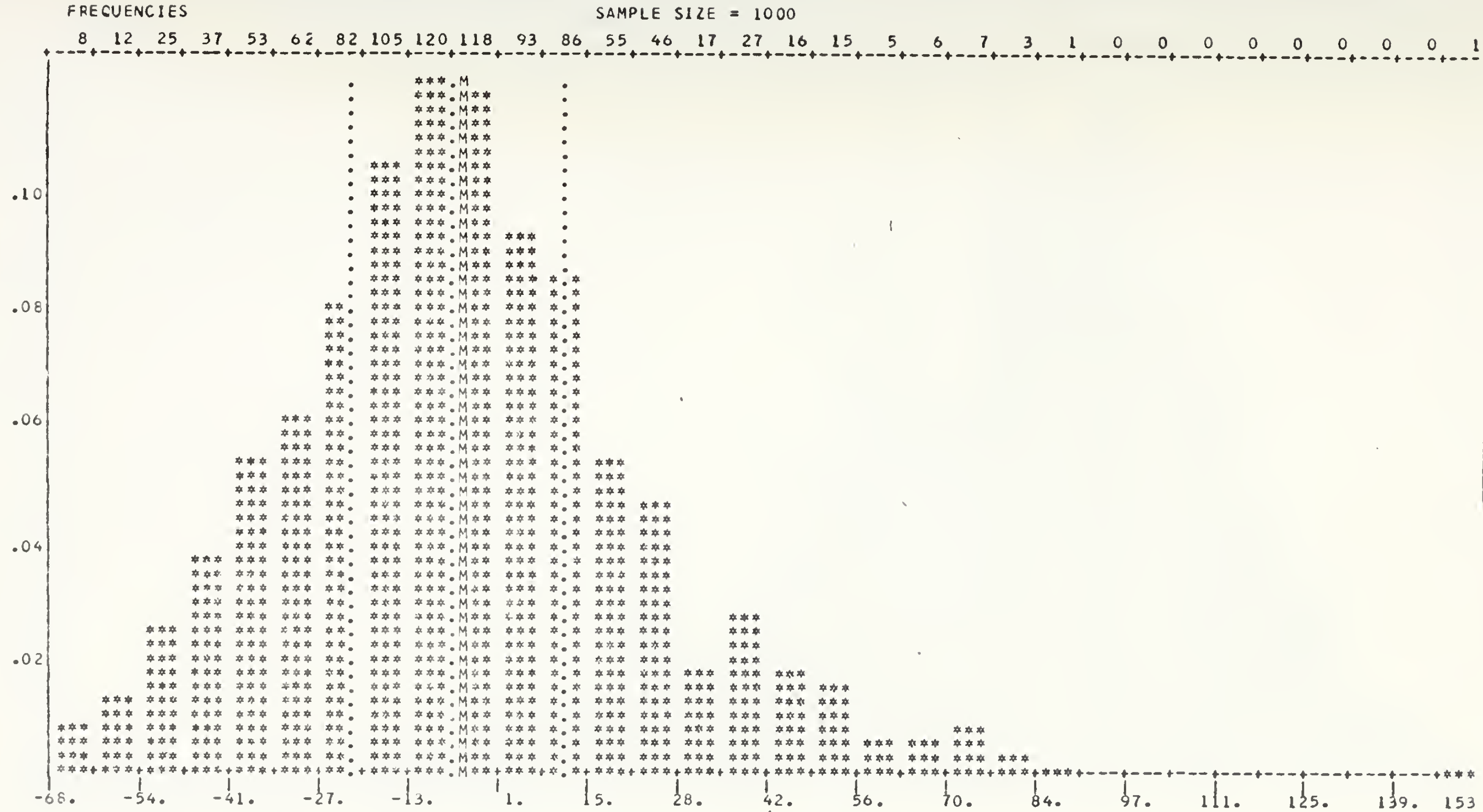
HIGHER CENTRAL MOMENTS	
M3	-1.037071E 01
M4	1.866673E 02
SKEWNESS	-7.456458E-01
KURTOSIS	2.580850E 00
BETA1	-1.033962E 01
BETA2	1.861210E 02

DISTRIBUTION		
MINIMUM		-1.600000E 01
.10 QUANTILE		-2.000000E 00
.25 QUANTILE	(HINGE)	0.0
.50 QUANTILE	(MEDIAN)	1.000000E 00
.75 QUANTILE	(HINGE)	3.000000E 00
.90 QUANTILE		4.000000E 00
MAXIMUM		7.000000E 00

ERROR IN SIGHT SETTING

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
30.	450.	3000.



CENTRAL TENDENCY	
MEAN	-4.718519E 00
MEDIAN	-6.402344E 00
TRIMEAN	-6.174316E 00
MIDMEAN	-6.147230E 00
MIDRANGE	4.225781E 01

SPREAD	
VARIANCE	7.215586E 02
STD DEV	2.686185E 01
COEF VAR	5.692855E 00
MEAN DEV	2.054533E 01
RANGE	2.208281E 02
MIDSPREAD	3.327539E 01

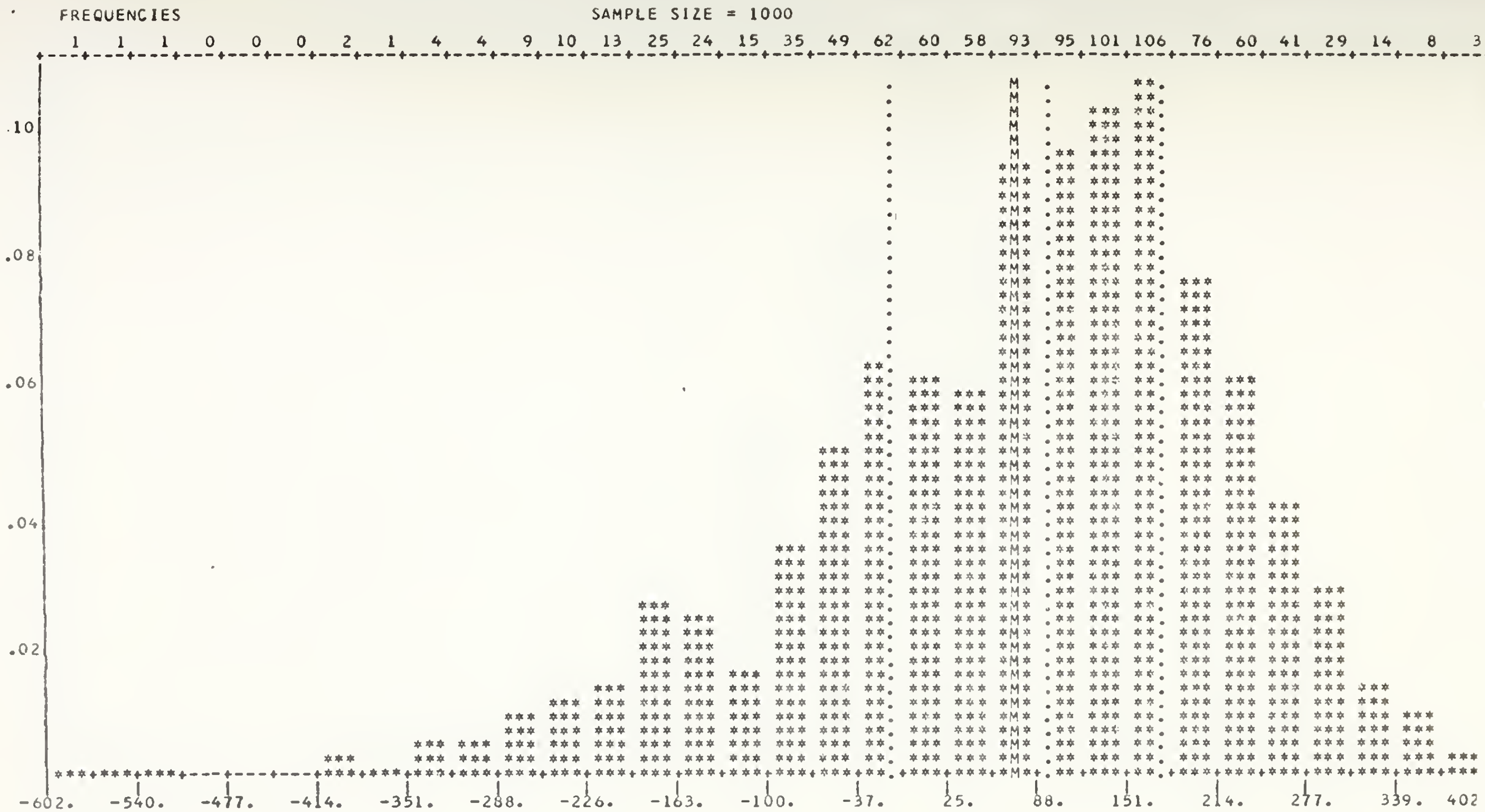
HIGHER CENTRAL MOMENTS	
M3	1.207627E 04
M4	2.273313E 06
SKEWNESS	6.230535E-01
KURTOSIS	1.366324E 00
BETA1	1.204006E 04
BETA2	2.267339E 06

DISTRIBUTION		
MINIMUM		-6.815625E 01
.10 QUANTILE		-3.839063E 01
.25 QUANTILE	(HINGE)	-2.258398E 01
.50 QUANTILE	(MEDIAN)	-6.402344E 00
.75 QUANTILE	(HINGE)	1.069141E 01
.90 QUANTILE		2.773438E 01
MAXIMUM		1.526719E 02

ERROR IN DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
30.	500.	5000.

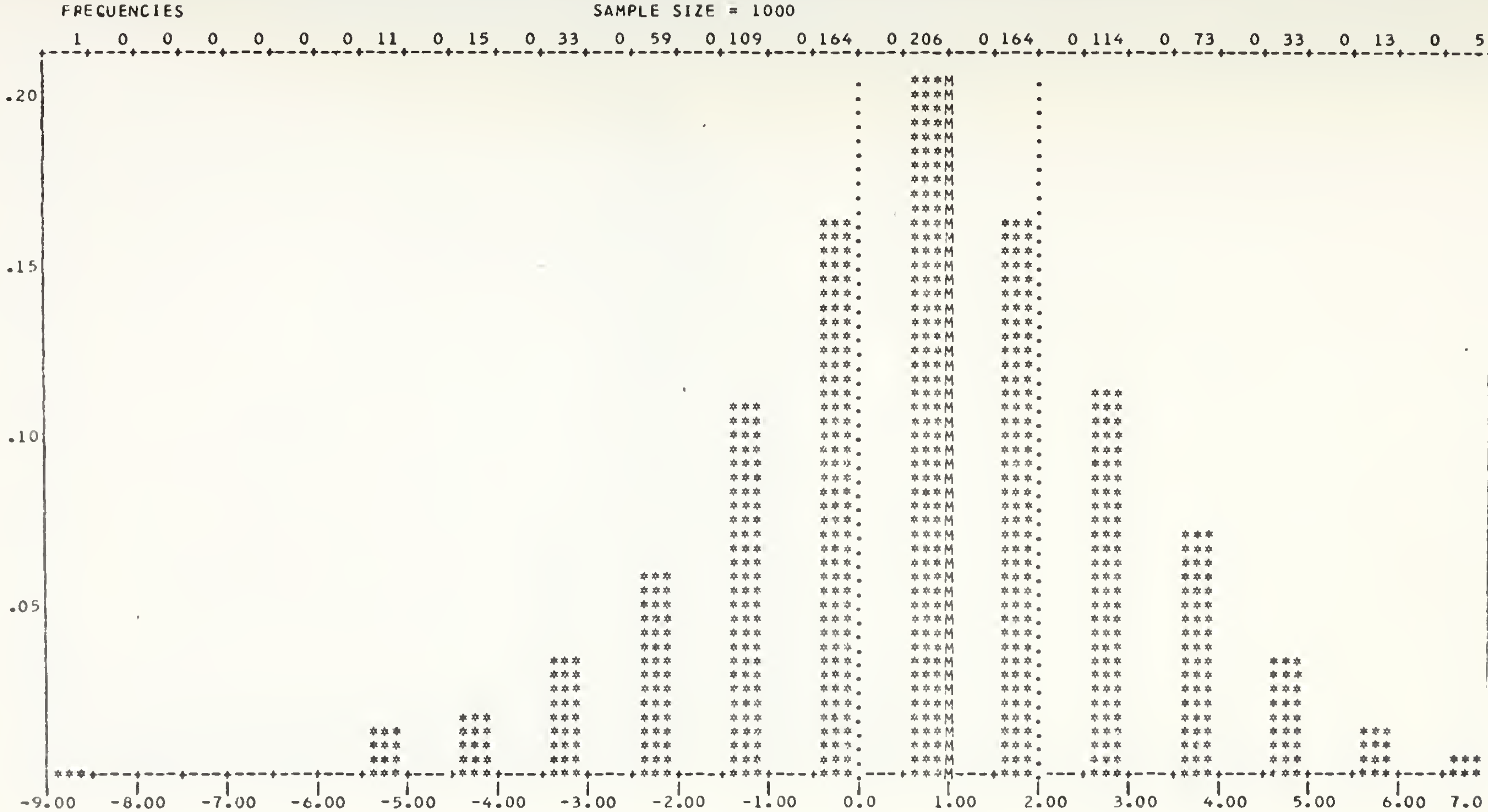


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION		
MEAN	7.742320E 01	VARIANCE	2.073498E 04	M3	-2.290636E 06	MINIMUM		-6.022813E 02
MEDIAN	9.868164E 01	STD DEV	1.439965E 02	M4	1.689853E 09	.10 QUANTILE		-1.166680E 02
TRIMEAN	9.132910E 01	COEF VAR	1.859861E 00	SKEWNESS	-7.671861E-01	.25 QUANTILE	(HINGE)	-9.408203E 00
MIDMEAN	9.442783E 01	MEAN DEV	1.113410E 02	KURTOSIS	9.304457E-01	.50 QUANTILE	(MEDIAN)	9.868164E 01
MIDRANGE	-1.001074E 02	RANGE	1.004348E 03	BETA1	-2.283769E 06	.75 QUANTILE	(HINGE)	1.773613E 02
		MIDSPREAD	1.867695E 02	BETA2	1.685669E 09	.90 QUANTILE		2.433398E 02
						MAXIMUM		4.020664E 02

ERROR IN UNCORRECTED DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
30	500.	5000.

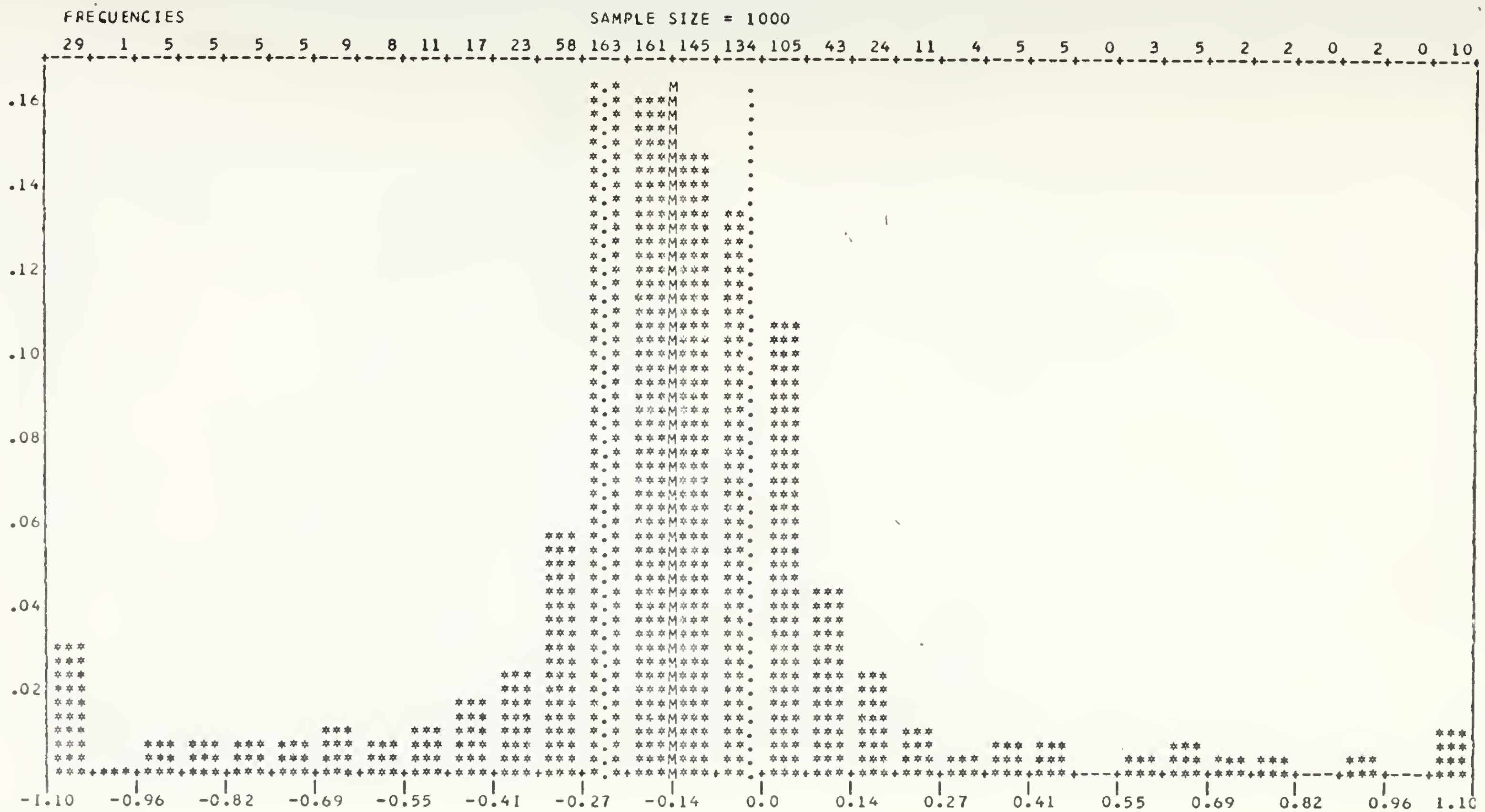


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	9.960000E-01	VARIANCE	4.844827E 00	M3	-2.076140E 00	MINIMUM	-9.000000E 00
MEDIAN	1.000000E 00	STD DEV	2.201097E 00	M4	7.986519E 01	.10 QUANTILE	-2.000000E 00
TRIMEAN	1.000000E 00	COEF VAR	2.209936E 00	SKEWNESS	-1.946881E-01	.25 QUANTILE (HINGE)	0.0
MIDMEAN	1.020000E 00	MEAN DEV	1.679999E 00	KURTOSIS	4.025240E-01	.50 QUANTILE (MEDIAN)	1.000000E 00
MIDRANGE	-1.000000E 00	RANGE	1.600000E 01	BETA1	-2.069917E 00	.75 QUANTILE (HINGE)	2.000000E 00
		MIDSPREAD	2.000000E 00	BETA2	7.968634E 01	.90 QUANTILE	4.000000E 00
						MAXIMUM	7.000000E 00

ERROR IN SIGHT SETTING

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
30.	500.	5000.

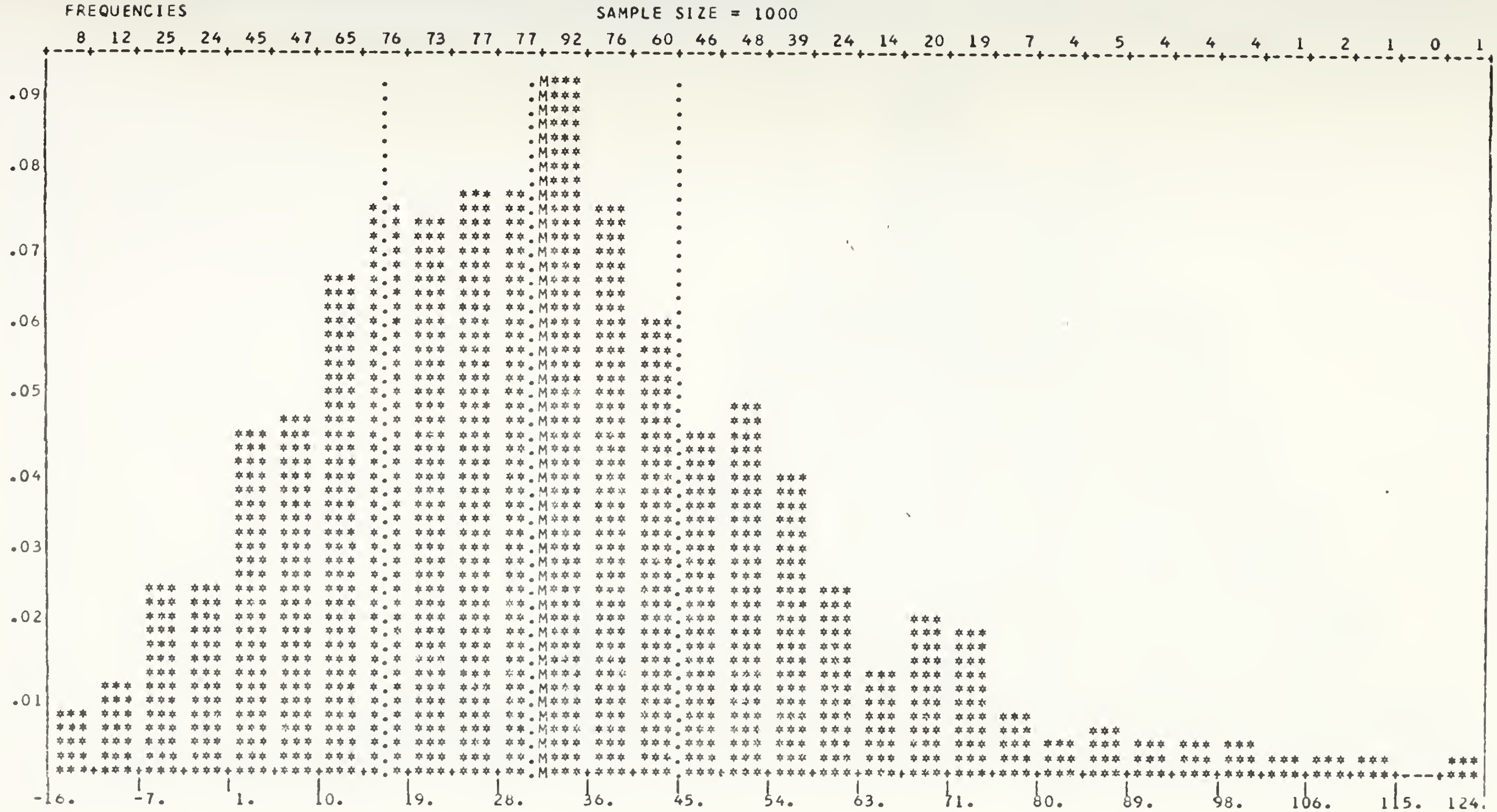


CENTRAL TENDENCY		SPREAO		HIGHER CENTRAL MOMENTS		OISTRIBUTION	
MEAN	-1.461177E-01	VARIANCE	8.951271E-02	M3	-2.607987E-03	MINIMUM	-1.099999E 00
MEDIAN	-1.375456E-01	STD DEV	2.991868E-01	M4	6.494153E-02	.10 QUANTILE	-4.035140E-01
TRIMEAN	-1.332284E-01	COEF VAR	2.047573E 00	SKEWNESS	-9.738189E-02	.25 QUANTILE (HINGE)	-2.393045E-01
MIDMEAN	-1.352168E-01	MEAN DEV	1.869187E-01	KURTOSIS	5.105004E 00	.50 QUANTILE (MEDIAN)	-1.375456E-01
MIORANGE	0.0	RANGE	2.199999E 00	BETA1	-2.600169E-03	.75 QUANTILE (HINGE)	-1.851802E-02
		MIOSPREAO	2.207865E-01	BETA2	6.472975E-02	.90 QUANTILE	8.965635E-02
						MAXIMUM	1.099999E 00

CORRECTEO ERROR/UNCORRECTEO ERROR

OESIRED OELIVERY

DIVE ANGLE	TRUE AIRSPEEO	RELEASE ALTITUDE
30.	500.	5000.

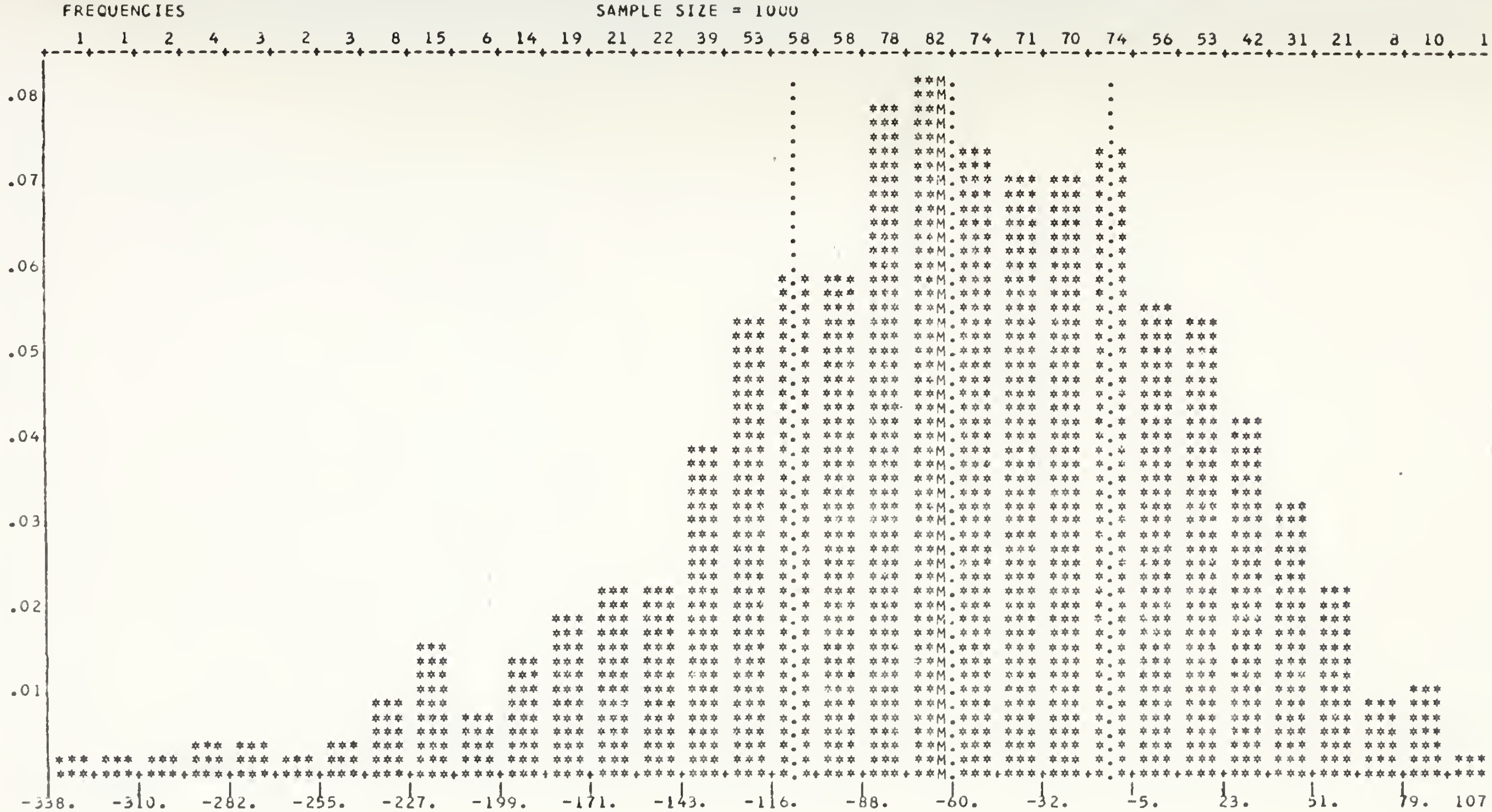


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	3.162369E 01	VARIANCE	4.917185E 02	M3	6.316648E 03	MINIMUM	-1.623828E 01
MEDIAN	3.016345E 01	STD DEV	2.217473E 01	M4	8.643069E 05	.10 QUANTILE	4.468506E 00
TRIMEAN	3.020804E 01	COEF VAR	7.012063E-01	SKEWNESS	5.793111E-01	.25 QUANTILE (HINGE)	1.599719E 01
MIDMEAN	3.005846E 01	MEAN DEV	1.732478E 01	KURTOSIS	5.746613E-01	.50 QUANTILE (MEDIAN)	3.016345E 01
MIDRANGE	5.380212E 01	RANGE	1.400808E 02	BETA1	6.297715E 03	.75 QUANTILE (HINGE)	4.450806E 01
		MIDSPREAD	2.851096E 01	BETA2	8.622981E 05	.90 QUANTILE	5.979224E 01
						MAXIMUM	1.238425E 02

ERROR IN DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
45.	450.	4000.

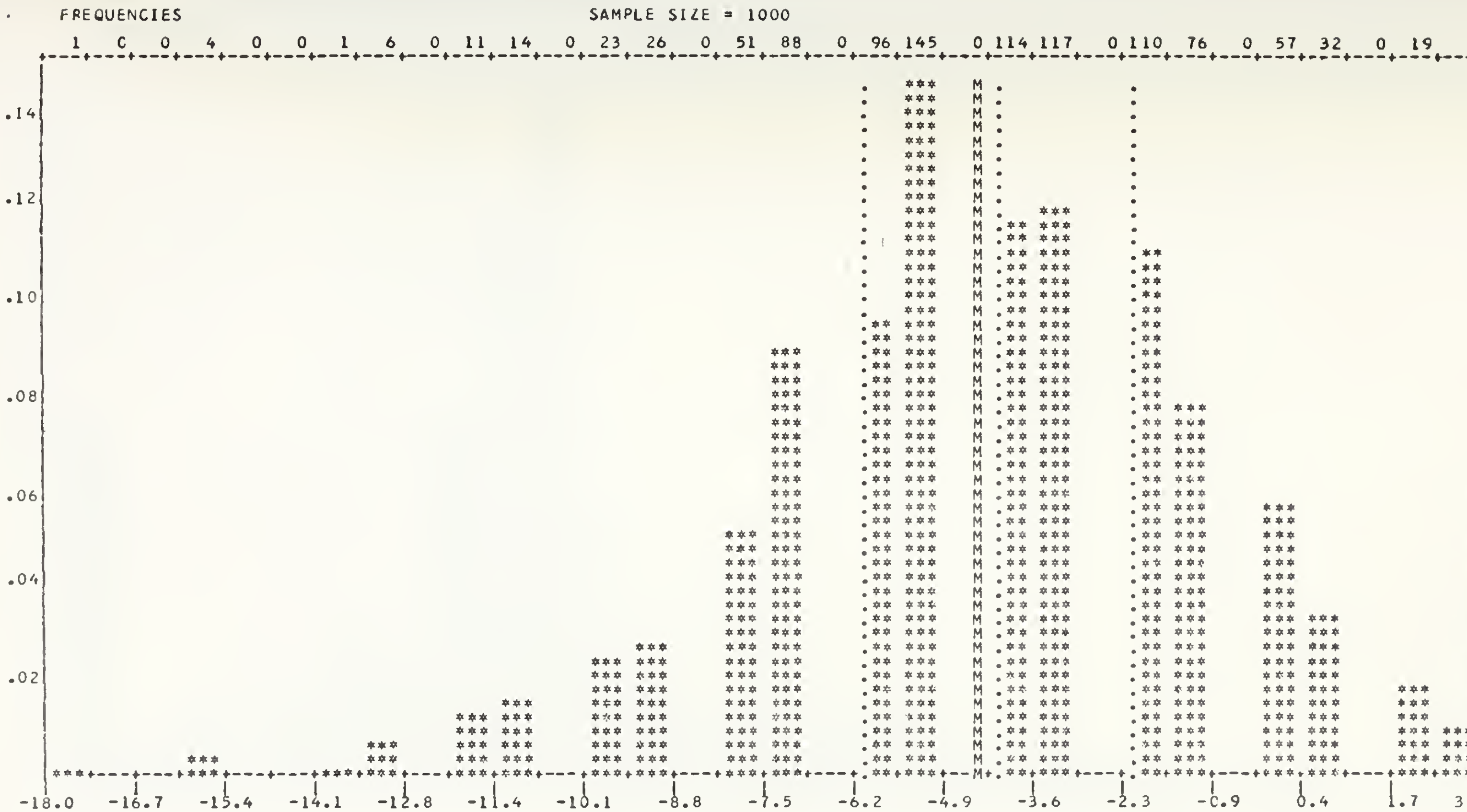


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-6.220845E 01	VARIANCE	5.289051E 03	M3	-2.122805E 05	MINIMUM	-3.379971E 02
MEDIAN	-5.843384E 01	STD DEV	7.272586E 01	M4	9.505205E 07	.10 QUANTILE	-1.568501E 02
TRIMEAN	-5.885822E 01	COEF VAR	1.169066E 00	SKEWNESS	-5.518785E-01	.25 QUANTILE (HINGE)	-1.071661E 02
MIDMEAN	-5.718930E 01	MEAN DEV	5.734593E 01	KURTOSIS	3.978653E-01	.50 QUANTILE (MEDIAN)	-5.843384E 01
MIDRANGE	-1.156841E 02	RANGE	4.446260E 02	BETA1	-2.116441E 05	.75 QUANTILE (HINGE)	-1.139905E 01
		MIDSPREAD	9.576709E 01	BETA2	9.483942E 07	.90 QUANTILE	2.694238E 01
						MAXIMUM	1.066289E 02

ERROR IN UNCORRECTED DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
45.	450.	4000.

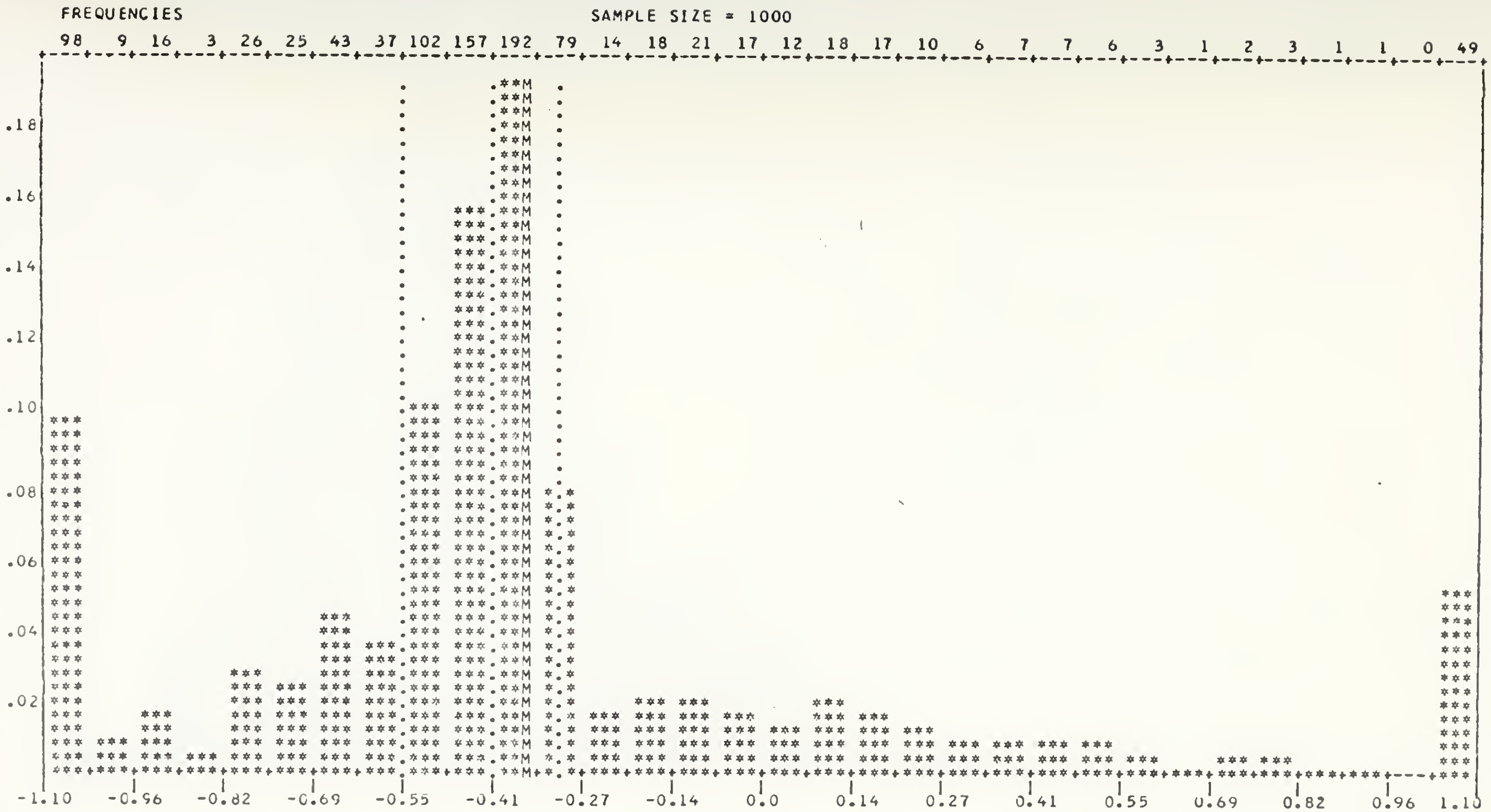


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-4.254999E 00	VARIANCE	1.038636E 01	M3	-1.443610E 01	MINIMUM	-1.800000E 01
MEDIAN	-4.000000E 00	STD DEV	3.222788E 00	M4	3.883508E 02	.10 QUANTILE	-8.000000E 00
TRIMEAN	-4.000000E 00	COEF VAR	7.574121E-01	SKEWNESS	-4.312753E-01	.25 QUANTILE (HINGE)	-6.000000E 00
MIDMEAN	-4.127999E 00	MEAN DEV	2.514999E 00	KURTOSIS	5.999584E-01	.50 QUANTILE (MEDIAN)	-4.000000E 00
MIDRANGE	-7.500000E 00	RANGE	2.100000E 01	BETA1	-1.439282E 01	.75 QUANTILE (HINGE)	-2.000000E 00
		MIDSPREAD	4.000000E 00	BETA2	3.874436E 02	.90 QUANTILE	0.0
						MAXIMUM	3.000000E 00

ERROR IN SIGHT SETTING

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
45.	450.	4000.

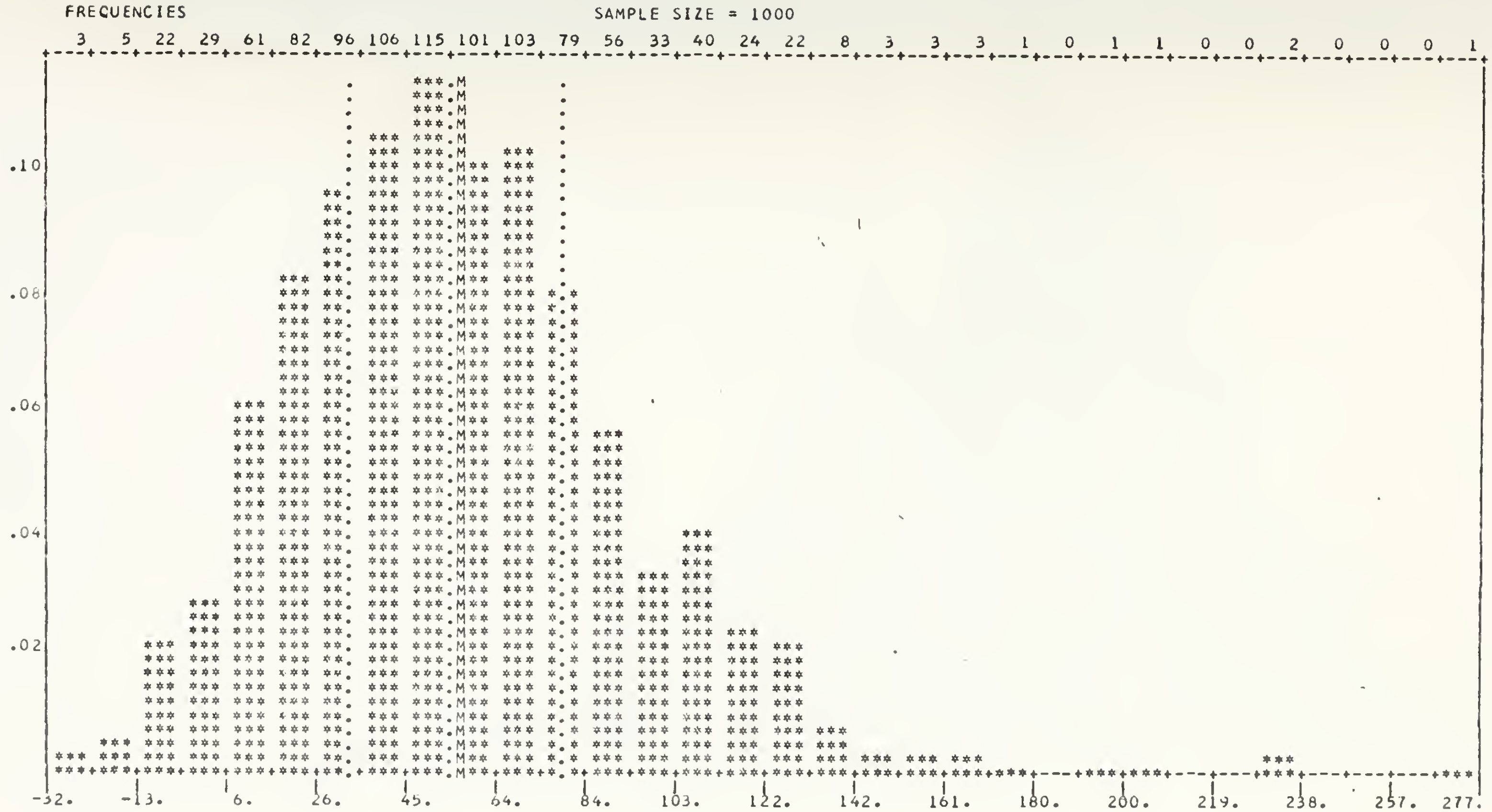


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-3.712570E-01	VARIANCE	2.320560E-01	M3	1.458954E-01	MINIMUM	-1.099999E 00
MEDIAN	-4.196115E-01	STD DEV	4.817219E-01	M4	2.947083E-01	.10 QUANTILE	-9.872640E-01
TRIMEAN	-4.303219E-01	COEF VAR	1.297543E 00	SKEWNESS	1.305125E 00	.25 QUANTILE (HINGE)	-5.622778E-01
MIDMEAN	-4.266163E-01	MEAN DEV	3.034773E-01	KURTOSIS	2.472766E 00	.50 QUANTILE (MEDIAN)	-4.196115E-01
MIDRANGE	0.0	RANGE	2.199999E 00	BETA1	1.454580E-01	.75 QUANTILE (HINGE)	-3.197874E-01
		MIDSPREAD	2.424904E-01	BETA2	2.938521E-01	.90 QUANTILE	1.816664E-01
						MAXIMUM	1.099999E 00

CORRECTED ERROR/UNCORRECTED ERROR

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
45.	450.	4000.

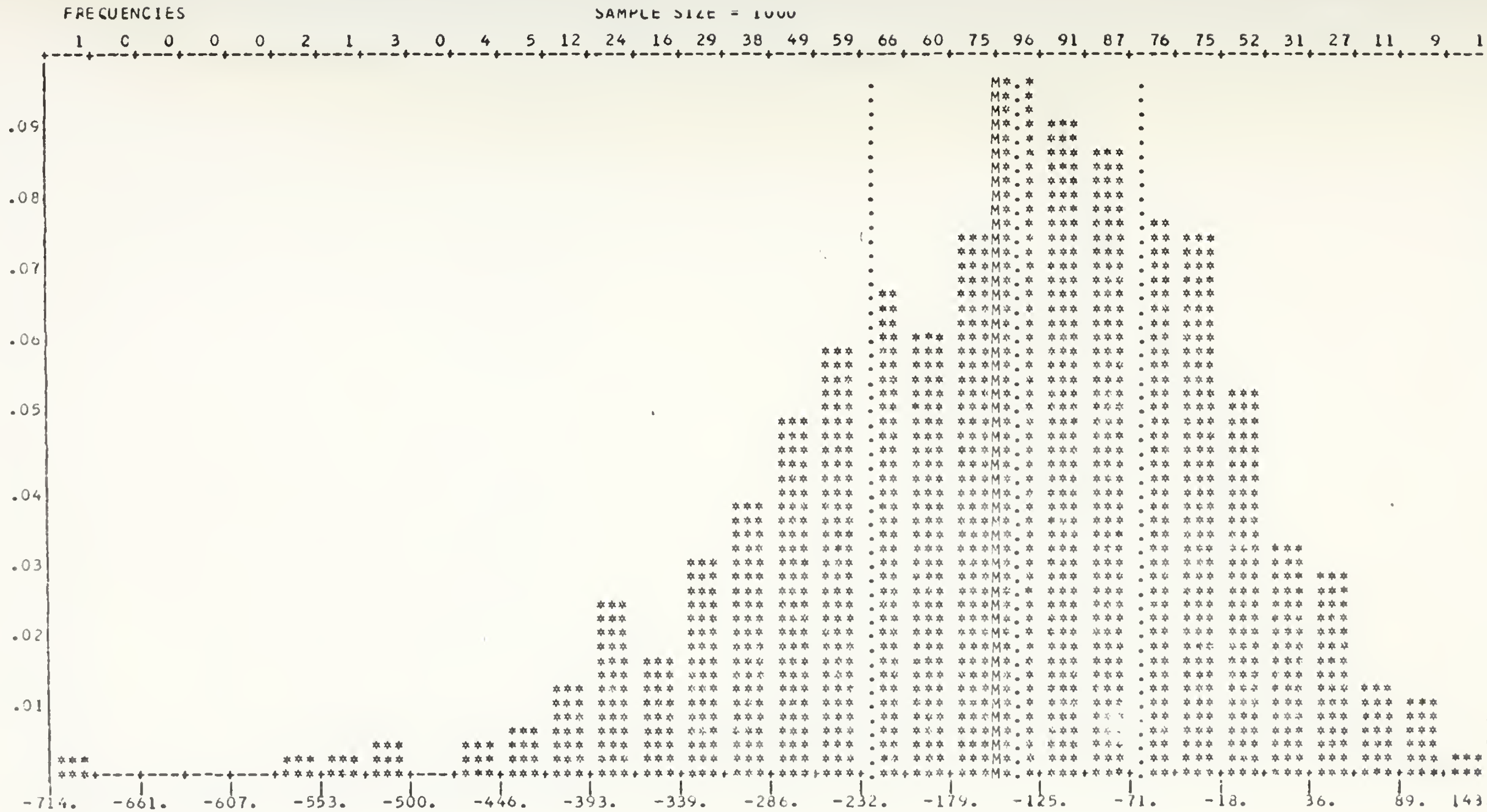


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	5.634285E 01	VARIANCE	1.336075E 03	M3	4.058251E 04	MINIMUM	-3.216138E 01
MEDIAN	5.316016E 01	STD DEV	3.655237E 01	M4	9.303374E 06	.10 QUANTILE	1.416016E 01
TRIMEAN	5.345117E 01	COEF VAR	6.487490E-01	SKEWNESS	8.309835E-01	.25 QUANTILE (HINGE)	3.049023E 01
MIDMEAN	5.353720E 01	MEAN DEV	2.820894E 01	KURTOSIS	2.211694E 00	.50 QUANTILE (MEDIAN)	5.316016E 01
MIDRANGE	1.223119E 02	RANGE	3.089465E 02	BETA1	4.046085E 04	.75 QUANTILE (HINGE)	7.699414E 01
		MIDSPREAD	4.650391E 01	BETA2	9.276855E 06	.90 QUANTILE	1.045898E 02
						MAXIMUM	2.767852E 02

ERROR IN DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
45.	500.	6000.

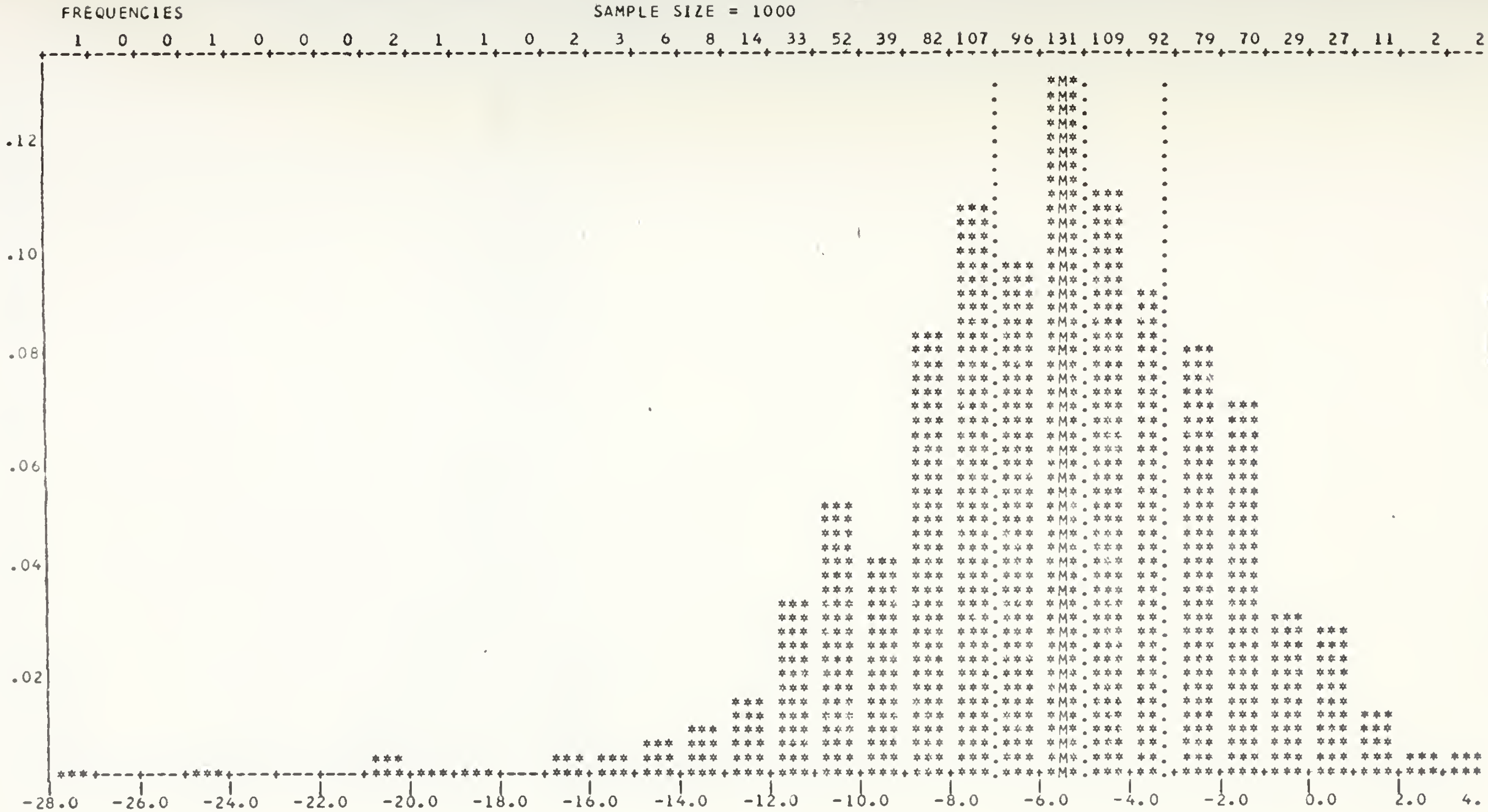


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-1.487407E 02	VARIANCE	1.443602E 04	M3	-8.509351E 05	MINIMUM	-7.140742E 02
MEDIAN	-1.336855E 02	STD DEV	1.201500E 02	M4	6.882655E 08	.10 QUANTILE	-3.092461E 02
TRIMEAN	-1.390029E 02	COEF VAR	8.077813E-01	SKEWNESS	-4.905975E-01	.25 QUANTILE (HINGE)	-2.259609E 02
MIDMEAN	-1.397101E 02	MEAN DEV	9.559491E 01	KURTOSIS	3.026381E-01	.50 QUANTILE (MEDIAN)	-1.336855E 02
MIDRANGE	-2.856897E 02	RANGE	8.567690E 02	BETA1	-8.483842E 05	.75 QUANTILE (HINGE)	-6.267969E 01
		MIDSPREAD	1.632813E 02	BETA2	6.867610E 08	.90 QUANTILE	-6.542969E 00
						MAXIMUM	1.426948E 02

ERROR IN UNCORRECTED DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
45.	500.	6000.

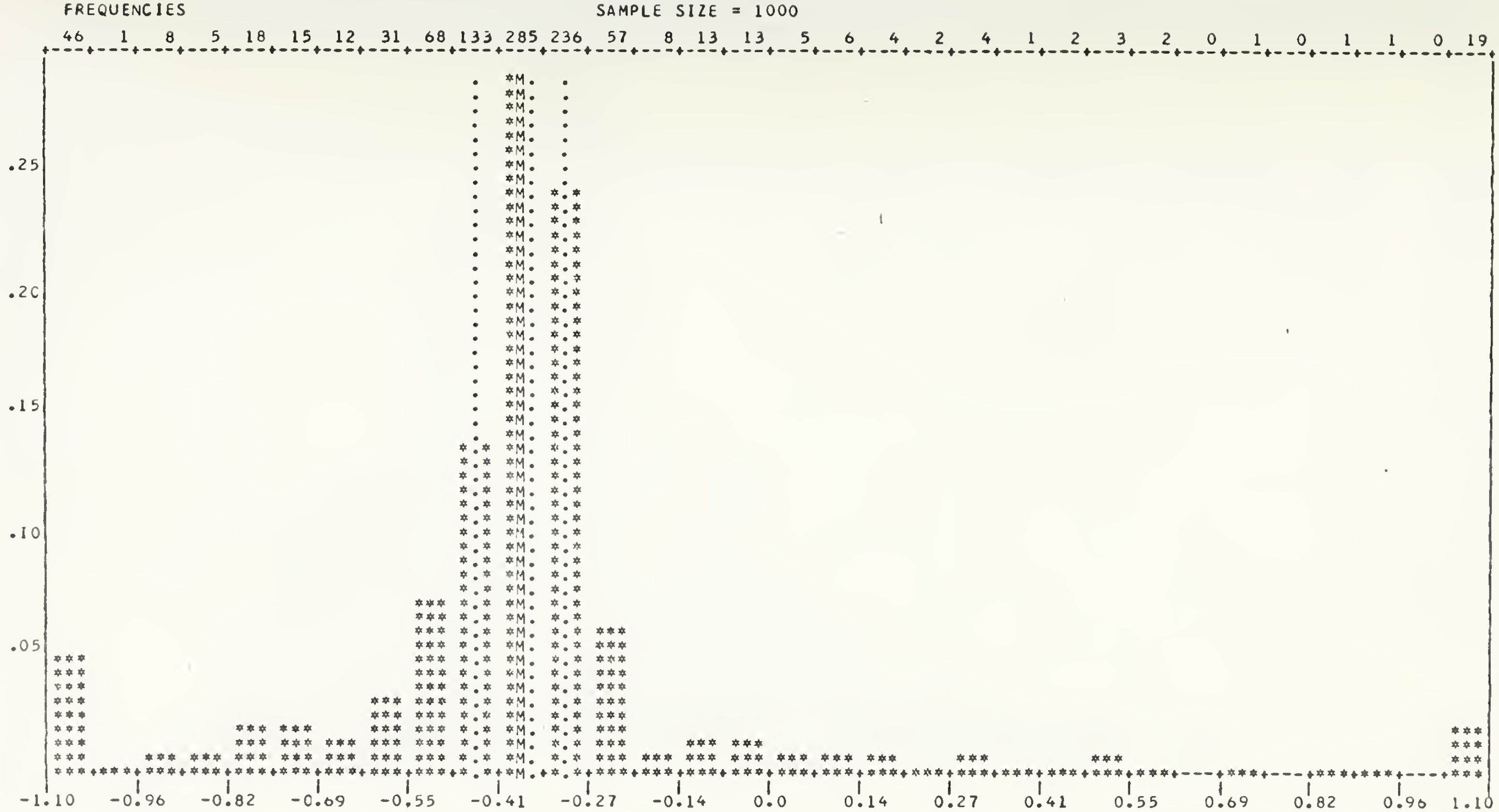


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-5.308999E 00	VARIANCE	1.305657E 01	M3	-3.375133E 01	MINIMUM	-2.800000E 01
MEDIAN	-5.000000E 00	STD DEV	3.613388E 00	M4	9.174370E 02	.10 QUANTILE	-1.000000E 01
TRIMEAN	-5.000000E 00	COEF VAR	6.806157E-01	SKEWNESS	-7.153971E-01	.25 QUANTILE (HINGE)	-7.000000E 00
MIDMEAN	-5.134000E 00	MEAN DEV	2.764999E 00	KURTOSIS	2.381680E 00	.50 QUANTILE (MEDIAN)	-5.000000E 00
MIDRANGE	-1.200000E 01	RANGE	3.200000E 01	BETA1	-3.365015E 01	.75 QUANTILE (HINGE)	-3.000000E 00
		MIDSPREAD	4.000000E 00	BETA2	9.147388E 02	.90 QUANTILE	-1.000000E 00
						MAXIMUM	4.000000E 00

ERROR IN SIGHT SETTING

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
45.	500.	6000.

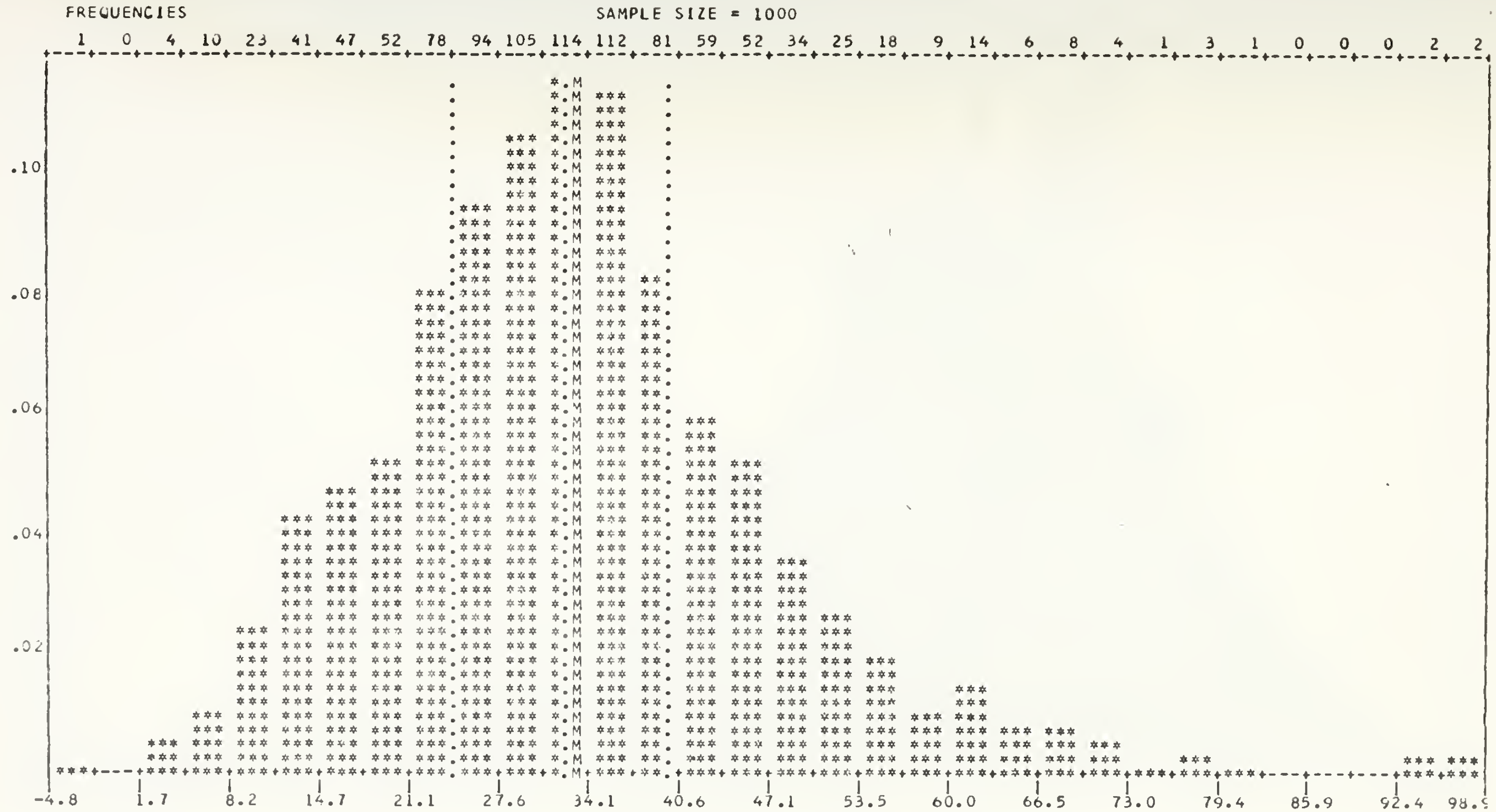


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-3.755614E-01	VARIANCE	1.001533E-01	M3	5.434490E-02	MINIMUM	-1.099999E 00
MEDIAN	-3.714702E-01	STD DEV	3.164701E-01	M4	1.192550E-01	.10 QUANTILE	-6.642038E-01
TRIMEAN	-3.761730E-01	COEF VAR	8.426586E-01	SKEWNESS	1.714592E 00	.25 QUANTILE (HINGE)	-4.492080E-01
MIDMEAN	-3.734587E-01	MEAN DEV	1.672127E-01	KURTOSIS	8.889016E 00	.50 QUANTILE (MEDIAN)	-3.714702E-01
MIDRANGE	0.0	RANGE	2.199999E 00	BETA1	5.418198E-02	.75 QUANTILE (HINGE)	-3.125439E-01
		MIDSPREAD	1.366642E-01	BETA2	1.188381E-01	.90 QUANTILE	-2.355447E-01
						MAXIMUM	1.099999E 00

CORRECTED ERROR/UNCORRECTED ERROR

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
45.	500.	6000.

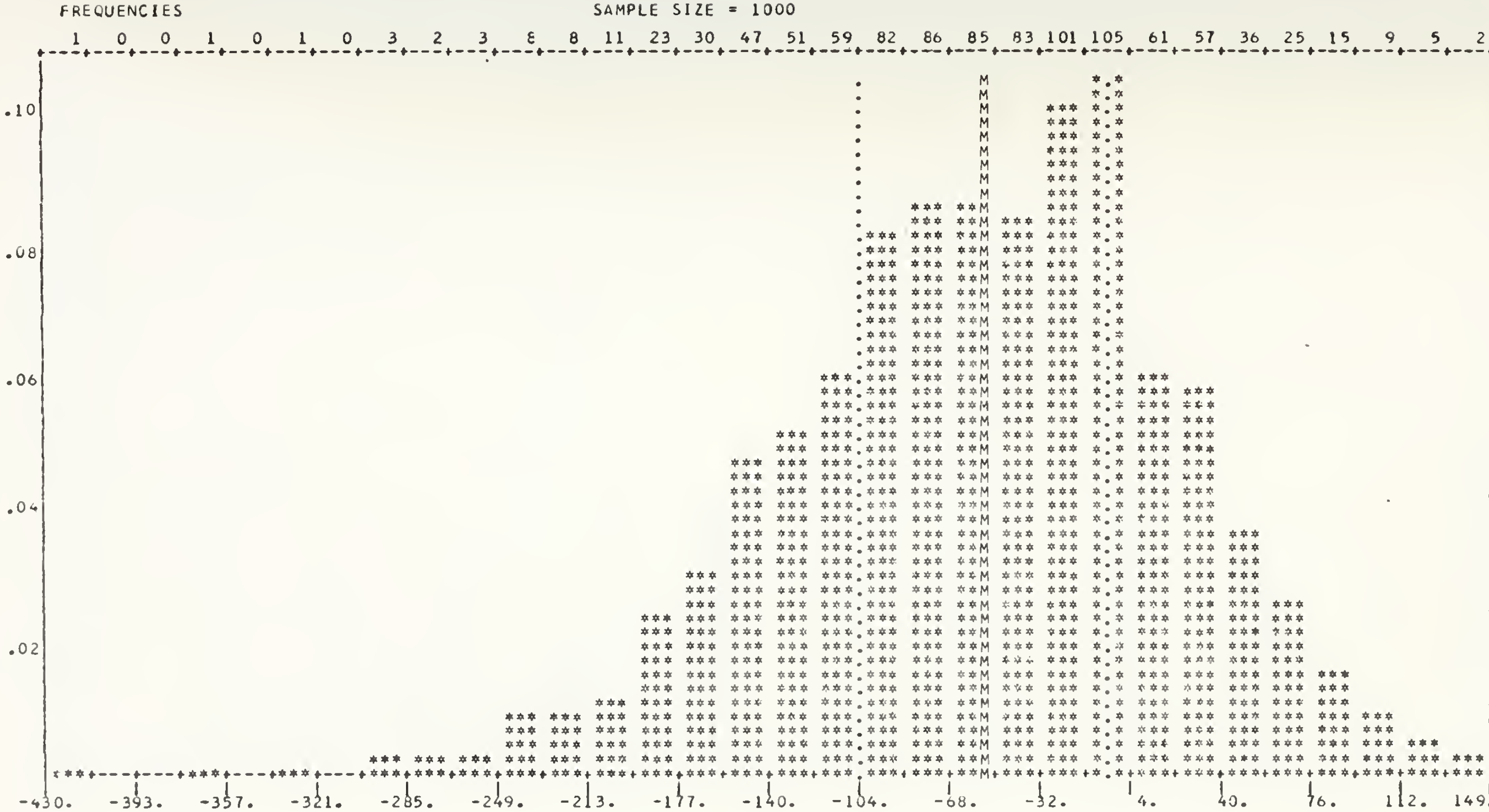


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	3.294940E 01	VARIANCE	1.846902E 02	M3	2.005776E 03	MINIMUM	-4.751465E 00
MEDIAN	3.210962E 01	STD DEV	1.359008E 01	M4	1.658707E 05	.10 QUANTILE	1.633008E 01
TRIMEAN	3.209296E 01	COEF VAR	4.124529E-01	SKEWNESS	7.991283E-01	.25 QUANTILE (HINGE)	2.432361E 01
MIDMEAN	3.203191E 01	MEAN DEV	1.023254E 01	KURTOSIS	1.862747E 00	.50 QUANTILE (MEDIAN)	3.210962E 01
MIDRANGE	4.705103E 01	RANGE	1.036050E 02	BETA1	1.999763E 03	.75 QUANTILE (HINGE)	3.962898E 01
		MIDSPREAD	1.550537E 01	BETA2	1.654116E 05	.90 QUANTILE	4.919019E 01
						MAXIMUM	9.885352E 01

ERROR IN DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
60.	500.	7000.

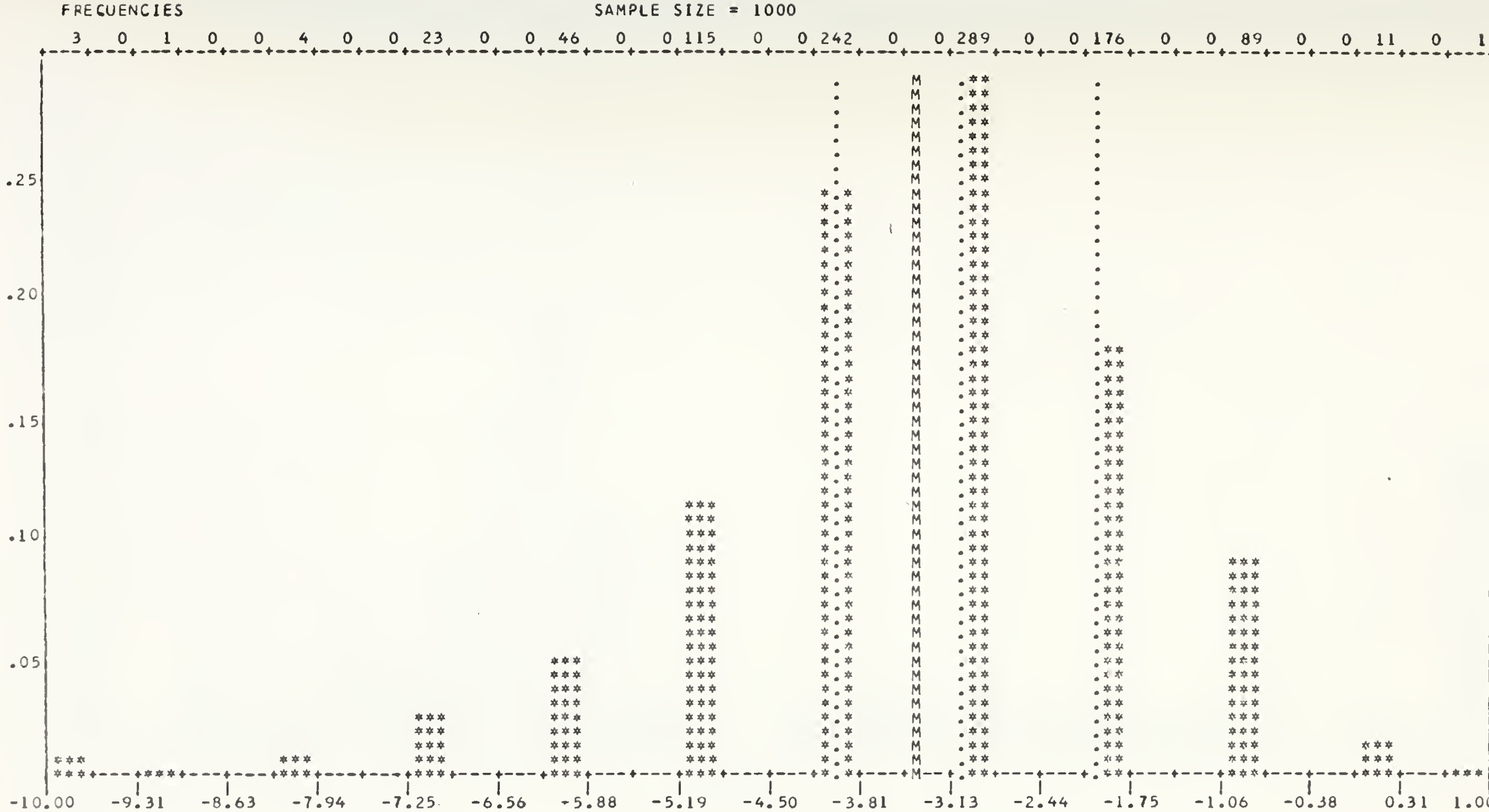


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-5.545532E 01	VARIANCE	5.885574E 03	M3	-2.073315E 05	MINIMUM	-4.295000E 02
MEDIAN	-5.126025E 01	STD DEV	7.671750E 01	M4	1.270988E 08	.10 QUANTILE	-1.553965E 02
TRIMEAN	-5.230530E 01	COEF VAR	1.383410E 00	SKEWNESS	-4.591790E-01	.25 QUANTILE (HINGE)	-1.036487E 02
MIDMEAN	-5.071989E 01	MEAN DEV	6.085938E 01	KURTOSIS	6.691370E-01	.50 QUANTILE (MEDIAN)	-5.126025E 01
MIDRANGE	-1.404390E 02	RANGE	5.781221E 02	BETA1	-2.067100E 05	.75 QUANTILE (HINGE)	-3.052002E 00
		MIDSPREAD	1.005967E 02	BETA2	1.267980E 08	.90 QUANTILE	3.689746E 01
						MAXIMUM	1.486221E 02

ERROR IN UNCORRECTED DOWN RANGE TRAVEL

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
60.	500.	7000.

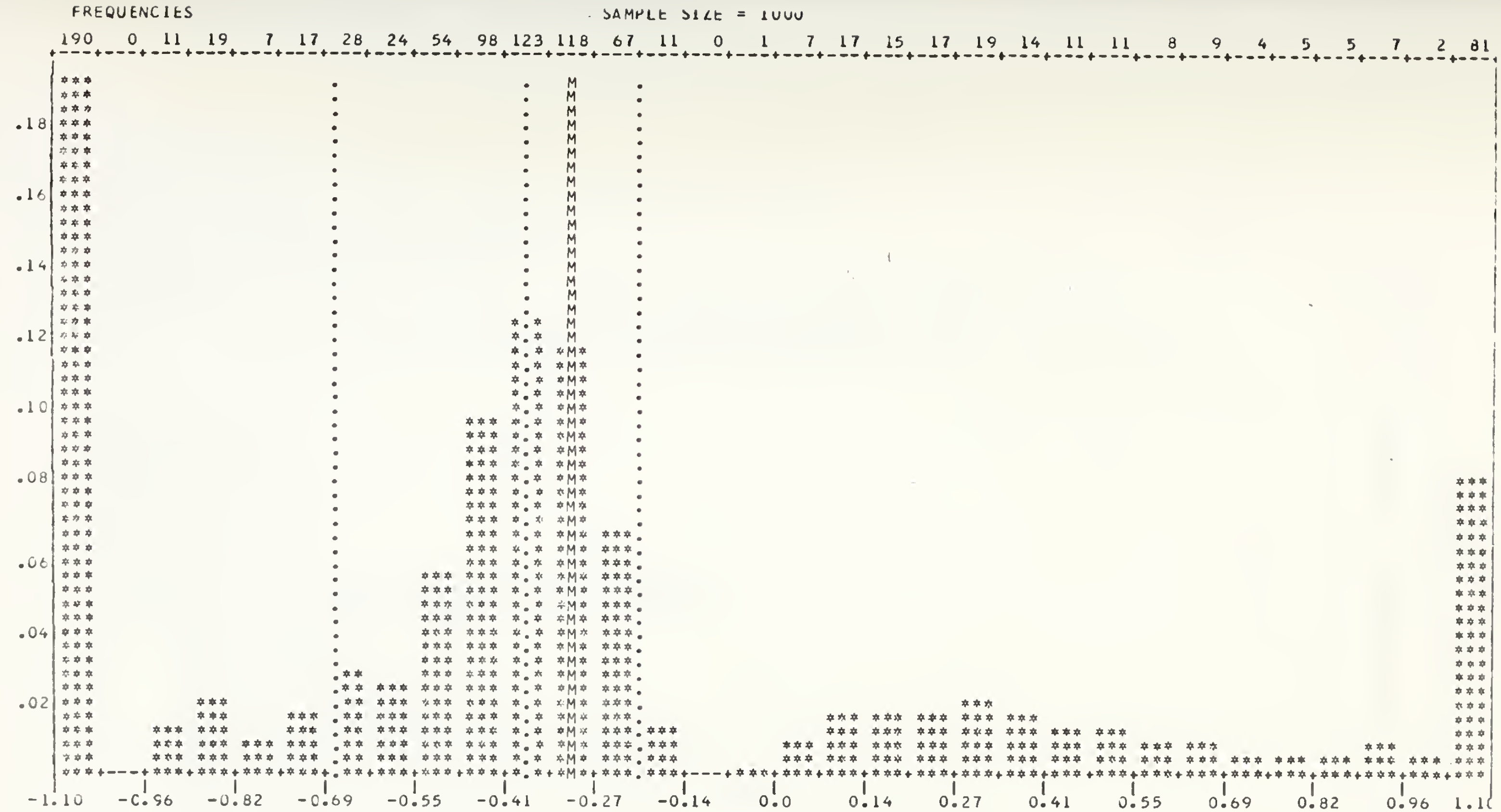


CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-3.358000E 00	VARIANCE	2.288123E 00	M3	-1.876755E 00	MINIMUM	-1.000000E 01
MEDIAN	-3.000000E 00	STD DEV	1.512654E 00	M4	2.104114E 01	.10 QUANTILE	-5.000000E 00
TRIMEAN	-3.000000E 00	COEF VAR	4.504629E-01	SKEWNESS	-5.422363E-01	.25 QUANTILE (HINGE)	-4.000000E 00
MIDMEAN	-3.313999E 00	MEAN DEV	1.139999E 00	KURTOSIS	1.018929E 00	.50 QUANTILE (MEDIAN)	-3.000000E 00
MIDRANGE	-4.500000E 00	RANGE	1.100000E 01	BETA1	-1.871130E 00	.75 QUANTILE (HINGE)	-2.000000E 00
		MIDSPREAD	2.000000E 00	BETA2	2.098833E 01	.90 QUANTILE	-1.000000E 00
						MAXIMUM	1.000000E 00

ERROR IN SIGHT SETTING

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
60.	500.	7000.



CENTRAL TENDENCY		SPREAD		HIGHER CENTRAL MOMENTS		DISTRIBUTION	
MEAN	-3.086175E-01	VARIANCE	3.896763E-01	M3	1.984040E-01	MINIMUM	-1.099999E 00
MEDIAN	-3.810638E-01	STD DEV	6.242406E-01	M4	4.719672E-01	.10 QUANTILE	-1.099999E 00
TRIMEAN	-4.133854E-01	COEF VAR	2.022699E 00	SKEWNESS	8.156320E-01	.25 QUANTILE (HINGE)	-6.778698E-01
MIDMEAN	-3.947231E-01	MEAN DEV	4.447933E-01	KURTOSIS	1.081629E-01	.50 QUANTILE (MEDIAN)	-3.810638E-01
MIDRANGE	0.0	RANGE	2.199999E 00	BETA1	1.978092E-01	.75 QUANTILE (HINGE)	-2.135451E-01
		MIDSPREAD	4.643247E-01	BETA2	4.709889E-01	.90 QUANTILE	7.274188E-01
						MAXIMUM	1.099999E 00

CORRECTED ERROR/UNCORRECTED ERROR

DESIRED DELIVERY

DIVE ANGLE	TRUE AIRSPEED	RELEASE ALTITUDE
60.	500.	7000.

APPENDIX C

STATIC ACCURACY SIMULATION PROGRAM

```
// EXEC FORTCLG,REGION.GO=100K
//FORT.SYSIN DD *
      REAL*4 DX(2)/-200.,200./,DELT(2)/-5.,5./
      SINE(X)=SIN(X*.0174533)
      COT(X)=COTAN(X*.0174533)
      ATAN1(X)=ATAN(X)/.0174533
    1 FORMAT(4F10.0)
   10 FORMAT(1H0,T33,'TABLE 1 SIMULATION OF DTHET AND DX''')
   11 FORMAT(1H0,T30,'DESIRED DIVE',T45,'ACTUAL DIVE',T60,'DX',
     1 T65,'CORRECTION ALT',T85,'DTHET',T105,'DX''')
   12 FORMAT(1X,T30,F10.5,T40,F10.5,T55,F7.1,T65,F10.2,T80,E15.7,
     1 T100.E15.7)
   13 FORMAT(1X,' ')
      WRITE(6,9)
    9 FORMAT(1H1,' ')
      DO 20 I=1,15
   20 WRITE(6,13)
      WRITE(6,11)
      DO 100 I=1,6
      READ(5,1) THET,STEEP,SHAL,RELALT
      CORALT=760.5*SINE(THET)*3.+RELALT
        DO 50 J=1,2
        ATHET=THET+DELT(J)
         DO 50 K=1,2
         X=CORALT*COT(ATHET)
         DTHET=ATAN1(CORALT/(X-DX(K)))-ATHET
         IF ( DTHET .GT. 0.0) GO TO 40
         DXP=DTHET*SHAL
         WRITE(6,12) THET,ATHET,DX(K),CORALT,DTHET,DXP
         GO TO 50
   40    DXP=DTHET*STEEP
         WRITE(6,12) THET,ATHET,DX(K),CORALT,DTHET,DXP
   50 CONTINUE
  100 CONTINUE
      DO 110 I=1,10
  110 WRITE(6,13)
      WRITE(6,10)
      STOP
      END
```

APPENDIX D

SIMULATION OF ANGLE OF ATTACK MODULE

```
BEGIN
 INTEGER ARRAY CO,DCO,B(0::21);
 FOR I:=0 UNTIL 21 DO
   READ(CO(I),DCO(I),B(I));
 BEGIN
 INTEGER PROCEDURE MIL(INTEGER VALUE CAS,THET) ;
 BEGIN
    INTEGER  PROCEDURE T(INTEGER VALUE CAS);
    BEGIN
    NUMBER(#FFFF AND BITSTRING( NUMBER(#7C) + NUMBER(BITSTRING(CAS* (
    NUMBER( BITSTRING( NUMBER(#7FD) - NUMBER( BITSTRING (CAS*
    NUMBER(#53)) SHR 4 )) SHR 2)))SHR 7)) SHR 3)
  END T;
  INTEGER PROCEDURE ICOS(INTEGER VALUE THET );
  BEGIN
  CO(NUMBER( BITSTRING(THET) SHR 2)) -NUMBER(BITSTRING(   NUMBER
    (BITSTRING( THET) AND #3) * DCO( NUMBER( BITSTRING(THET) SHR 2)))
    SHR 1)
  END ICOS;
 NUMBER( BITSTRING(ICOS(THET) *(  B(NUMBER(BITSTRING(THET) SHR 4)) -
         T(CAS))) SHR 9)
 END MIL;
 WRITE("DIVE","CAS","MIL");
 FOR I:= 0 STEP 10  UNTIL 60  DO
 FOR J:= 5    STEP 10 UNTIL 255  DO
  WRITE(I,J+295,MIL(J,I));
 END
 END.
```

APPENDIX E

FORECASTING SIMULATION

```
      CCMMON /POLY/NTERMS,BI(20),CI(20),DI(20)
      COMMON B(6,3),THET,TRST,SLUG,W
      REAL*4 WI(100)/100*1.0/
      DIMENSION XS(3),YX(3),XA(3),YA(3)
      DIMENSION X(100),Y(100),ERROR(100),PJM(100),PJ(100)
      DIMENSION YS(3)
      DIMENSION POY(2),YAP(2),YSP(2)
      DIMENSION ERORT(1000),ERAV(1000),ERSEC(1000)
      DIMENSION ERRS(4),DEVS(4)
      DIMENSION XMEAN(1000),YN
      DIMENSION XMEAN(1000),YMEAN(1000),YCN(1000),XCON(1000)
      DIMENSION HT(42),SPD(42)
      DIMENSION ZX(4)
      DATA DEVS/5000.,25.,3.,1500./
 DEFINITION OF TERMS
   THET =DIVE ANGLE
    TRST = THRUST
    SLUG= MASS
    W =WEIGHT
    B = AN ARRAY OF COEFFICIENTS TO BE USED BY DRAG
    NTERMS,BI,CI,DI  COEFFICIENTS TO BE USED BY
      THE ROUTINE WHICH GENERATES  ORTHOGONAL LOLYNOMIALS
    XS,YS     ONE SECOND SAMPLES
    XA,YA     AVERAGED SAMPLES
     X,Y    SAMPLES TO BE USED BY ORTHOGONAL POLYNOMIAL PREDICTION
  POY,YAP,YSP  PREDICTIONS BY ORTHOGONAL, AVERAGING, AND ONE
      SECOND SAMPLING SCHEMES
    ERORT,ERAV,ERSEC  THE ERROR OF THE ORTHOGONAL, AVERAGED, AND ONE SECOND
    PREDICTIONS
     DEVS  STANDARD DEVIATION OF ENTRY CONDITIONS
    XMEAN,YMEAN, YCN,  XCON   ARRAY  OF PSEUDO RANDOM
    VARIABLES
      TRUNC(X)=FLOAT(IFIX(X+.5))
      TRUN4(X)=FLOAT(IFIX(X*10+.5))/10
    STATEMENTS  TO CONVERT FLOATING POINT TO SIMULATED
    FOUR PLACE PRECISION
      CCIN(X)=-1.**IFIX(X+.5)
      STATEMENT TO GIVE A 'RANDOM' + OR - 1 IF X IS UNIFORM (0,1)
  101 FORMAT(E15.7)
      CALL OVFLOW
      RELALT=3000.
      NPOINT=20
      NTERMS=3
      W=420009
      W=42000.
      SLUG=W/32.17
      THET=30.
      ALT=6000.
```

```
      DO 2 I=1,6
      DO 1 J=1,3
      READ(5,101)B(I,J)
C READ INITIAL VALUES FOR DRAG COEFFICIENTS
    1 CONTINUE
    2 CONTINUE
      NNN=1000
      TRST=20000.
C SEED FOR LLRANDOM
      IX=7365247
      HT(1)=6000.
      SPD(1)=345.
C GET RANDOM VARIABLES
      CALL SNORM(IX,YMEAN,NNN)
      CALL SRAND(IX,YCN,NNN)
      CALL SRAND(IX,XCON,NNN)
      CALL SNORM(IX,XMEAN,NNN)
      VEL=345.
      ALIT=6000.
C TAKE THE INITIAL SAMPLES
      DO 10 I=2,42
      CALL INTEG(VEL,.1,ALIT)
      SPD(I)=VEL
      HT(I)=ALIT
   10 CONTINUE
      VEL=SPD(42)
      ALIT=HT(42)
      DELT=.5
      DO 20 K=1,20
      ALTL=ALIT
      SPL=VEL
      CALL INTEG(VEL,DELT,ALIT)
C SIMULATE THE DIVE TO RELEASE ALTITUDE
      IF (ABS(ALIT-RELALT) .LE. 10.) GO TO 25
      IF ( ALIT .GT. RELALT ) GO TO 20
      DELT=DELT*(ALTL-RELALT)/(ALTL-ALIT)
      ALIT=ALTL
      VEL=SPL
   20 CONTINUE
   25 CONTINUE
      DO 70 I=1,1000
      DO 60 K=1,42
C INTRODUCE INSTRUMENT ERRORS
      X(K)=TRUNC(HT(K)+COIN(XCON(I))*XMEAN(I)*10.)
      Y(K)=TRUN4(SPD(K)+YMEAN(I)*COIN(YCN(I))*.5)
   60 CONTINUE
      DO 50 J=1,3
C ONE SECOND SAMPLES
```

```
      XS(J)=X(1+(J-1)*10)
      YS(J)=Y(1+(J-1)*10)
   50 CONTINUE
   GENERATE ORTHOGONAL  POLYNOMIAL
      CALL ORPOL(NPOINT,X,Y,WI,ERROR,PJM,PJ)
   EVALUATE ORTHOGONAL  POLYNOMIAL
      PRDO=ORTVL(RELALT)
   MAKE PREDICTION BASED ON ONE SECOND SAMPLING
      CALL INTERP(XS,YS,RELALT,YPS)
      ERORT(I) =PRDO-VEL
      ERSEC(I)=YPS-VEL
      DO 55 J=1,3
      XAV=0.0
      YAV=0.0
   TAKE AVERAGED SAMPLES
      DO 53 K=1,4
      XAV=XAV+X(K+(9*(J-1)))
      YAV=YAV+Y(K+9*(J-1))
   53 CONTINUE
      XA(J)=XAV/4.
      YA(J)=YAV/4.
   55 CONTINUE
   MAKE A PREDICTION FROM AVERAGED SAMPLES
      CALL INTERP(XA,YA,RELALT,YPA)
      ERAV(I)=YPA-VEL
   70 CONTINUE
   PLOT THE DISTRIBUTIONS OF THE ERRORS
      STOP
      END
      CALL HISTG(ERAV,NNN,0)
      CALL HISTG(ERORT,NNN,0)
      CALL HISTG(ERSEC,NNN,0)
      SUBROUTINE ORPOL(NPOINT,X,F,W,ERROR,PJM1,PJ)
      COMMON /POLY/NTERMS,BI(20),CI(20),DI(20)
      DIMENSION X(100),F(100),W(100),ERROR(100),PJM1(100),PJ(100)
      DIMENSION S(20)
C     A SUBROUTINE TO GENERATE A SET OF ORTHOGONAL
C     POLYNOMIALS OF THE FORM P(X)=DI(1)$P0+DI(2)*P1...
C     WHERE P0=1 AND PJ+1=(X-BI(J+1))*PJ-C(J+1)*PJ-1
C     REFERENCE  ELEMENTARY NUMERICAL ANALYSIS BY CONTE AND DE BOOR
      DO 9 J=1,NTERMS
      BI(J)=0.
      DI(J)=0.
    9 S(J)=0.
      CI(1)=0.
      DO 10 I=1,NPOINT
      DI(1)=DI(1)+F(I)*W(I)
       BI(1)=BI(1)+W(I)*X(I)
```

```
10 S(1)=S(1)+W(1)
   DI(1)=DI(1)/S(1)
   DO 11 I=1,NPOINT
11 ERROR(I)=F(I)-DI(1)
   IF (NTERMS .EQ. 1)                       RETURN
   BI(1)=BI(1)/S(1)
   DO 12 I=1,NPOINT
   PJM1(I)=1.
12 PJ(I)=X(I)-BI(1)
   J=1
20 J=J+1
   DO 21 I=1,NPOINT
   P=PJ(I)*W(I)
   DI(J)=DI(J)+ERROR(I)*P
   P=P*PJ(I)
   BI(J)=BI(J)+X(I)*P
21 S(J)=S(J)+P
   DI(J)=DI(J)/S(J)
   DO 22 I=1,NPOINT
22 ERROR(I)=ERROR(I)-DI(J)*PJ(I)
   IF ( J.EQ. NTERMS)                       RETURN
   BI(J)=BI(J)/S(J)
   CI(J)=S(J)/S(J-1)
   DO 27 I=1,NPOINT
   P=PJ(I)
   PJ(I)=(X(I)-BI(J))*PJ(I)-CI(J)*PJM1(I)
27 PJM1(I)=P
                                            GO TO 20
   END
   FUNCTION ORTVL(X)
   COMMON /POLY/NTERMS,BI(20),CI(20),DI(20)
C  A FUNCTION TO EVALUATE THE ORTHOGONAL POLYNOMIALS
C  GENERATED BY ORTPOL.  REQUIRES COMMON LABELED 'POLY'
C  REFERENCE ELEMENTARY NUMERICAL ANALYSIS CONTE AND DE BOOR
   K=NTERMS
   ORTVL=DI(K)
   PREV=0.
10 K=K-1
   IF (K .EQ. 0)                            RETURN
   PREV2=PREV
   PREV=ORTVL
   ORTVL =DI(K)+(X-BI(K))*PREV-CI(K+1)*PREV2
   GO TO 10
   END
   SUBROUTINE INTERP(XI,YI,X,PY)
   DIMENSION XI(3),YI(3)
   F10=(YI(2)-YI(1))/(XI(2)-XI(1))
   F21=(YI(3)-YI(2))/(XI(3)-XI(2))
```

```
      F210=(F21-F10)/(XI(3)-XI(1))
      PY=YI(1)+(X-XI(1))*(F10+(X-XI(2))*F210)
      RETURN
      END
      SUBROUTINE INTEG(V,DT,XHT)
      COMMON B(6,3),THET,TRST,SLUG,W
      F1(X)=FUN1(X)
      F2(X,Y)=X*Y*1.689
      X1=DT*F1(V)
      Y1=F2(DT,V)
      X2=DT*F1(V+X1*.5)
      Y2=F2(DT,V+X1*.5)
      X3=DT*F1(V+X2*.5)
      Y3=F2(DT,V+X2*.5)
      X4=DT*F1(V+X3)
      Y4=F2(DT,V+X3)
      V=V+.1666667*(X1+2.*X2+2.*X3+X4)/1.689
      XHT=XHT-SIN(THET*.017453)*(Y1+2.*Y2+2.*Y3+Y4)*.1666667
      RETURN
      END
      FUNCTION FUN1(X)
      COMMON B(6,3),THET,TRST,SLUG,W
      FUN1=(TRST+SIN(THET*.017453)*W-DRAG(X))/SLUG
      RETURN
      END
      FUNCTION DRAG(TAS)
      COMMON B(6,3),THET,TRST,SLUG,W
      FX(B1,B2,B3,X)=B1+X*(B2+X*B3)
      IF(THET-10.) 10,20,40
   10 D20=FX(B(5,1),B(5,2),B(5,3),TAS)
      D10=FX(B(6,1),B(6,2),B(6,3),TAS)
      DRAG=(D10-D20)*(THET-20.)*(-.1)+D20
      RETURN
   20 DRAG=FX(B(6,1),B(6,2),B(6,3),TAS)
      RETURN
   40 IF(THET-20.)10,50,70
   50 DRAG=FX(B(5,1),B(5,2),B(5,3),TAS)
      RETURN
   60 D20=FX(B(5,1),B(5,2),B(5,3),TAS)
      D30=FX(B(4,1),B(4,2),B(4,3),TAS)
      DRAG=(D20-D30)*(THET-30.)*(-.1)+D30
      RETURN
   70 IF(THET-30.) 60,80,100
   80 DRAG=FX(B(4,1),B(4,2),B(4,3),TAS)
      RETURN
   90 D45=FX(B(3,1),B(3,2),B(3,3),TAS)
      D30=FX(B(4,1),B(4,2),B(4,3),TAS)
      DRAG=(D30-D45)*(THET-45.)*(-1./15.)+D45
```

```
      RETURN
  100 IF(THET-45.) 90,110,130
  110 DRAG=FX(B(3,1),B(3,2),B(3,3),TAS)
      RETURN
  120 D45=FX(B(3,1),B(3,2),B(3,3),TAS)
      D50=FX(B(2,1),B(2,2),B(2,3),TAS)
      DRAG=(D45-D50)*(THET-50.)*(-1./15.)+D50
       RETURN
  130 IF(THET-50.) 120,140,160
  140 DRAG=FX(B(2,1),B(2,2),B(2,3),TAS)
      RETURN
  150 D60=FX(B(1,1),B(1,2),B(1,3),TAS)
      D50=FX(B(2,1),B(2,2),B(2,3),TAS)
      DRAG=(D50-D60)*(THET-60.)*(-.1)+D60
      RETUFN
  160 IF(THET-60.)150,170,150
  170 DRAG=FX(B(1,1),B(1,2),B(1,3),TAS)
      RETURN
       END
```

APPENDIX F

DELIVERY ACCURACY COMPARISON

```
// EXEC FORTCLG,REGION.GO=120K
//FORT.SYSIN DD *
      DIMENSION EREN(4000),ZX(4),CX(4),EREAD(2),CRX(2),ERROR(10)
     1,EMILS(1000),EDRT(1000),EDRTU(1000),PER(1000)
      COMMON B(6,3),THET,TRST,SLUG,W
      LOGICAL FLAG
      DATA VE/7.2/
      DATA NN/1000/
      DATA ZX/200.,10.,2.5,750./
      DATA XMAL,XMAS,XMDI,XMTR/6000.,350.,28.5,18000./
      COIN(X)=-1.**(IFIX(X+.5))
      TRUN4(X)=FLOAT(IFIX(X*10.+.5))/10.
      TRUNC(X)=FLOAT(IFIX(X+.5))
    1 FORMAT(E15.7)
    2 FORMAT(I7)
    3 FORMAT(F10.0)
    4 FORMAT(4F10.0)
    5 FORMAT(1H0,T10,'DESIRED DELIVERY',//
     11X,'DIVE ANGLE',T20,'TRUE AIRSPEED',T40,'RELEASE ',
     2'ALTITUDE'//1X,F10.0,T20,F10.0,T45,F10.0)
  101 FORMAT(1X,'ERROR IN SIGHT SETTING')
  102 FORMAT(1X,'ERROR IN DOWN RANGE TRAVEL')
  103 FORMAT(1X,'ERROR IN UNCORRECTED DOWN RANGE TRAVEL')
  104 FORMAT(1X,'CORRECTED ERROR/UNCORRECTED ERROR')
      CALL OVFLOW
      W=42000.
      SLUG=1305.56
      READ(5,1)((B(I,J),J=1,3),I=1,6)
      READ(5,2)IX
      DO 310 II=1,6
      READ(5,3)(ERROR(I),I=1,10)
      READ(5,4)XMAL,XMAS,XMDI,XMTR
      CALL SNORM(IX,EREN,4000)
      DO 300 KK=1,NN
      CALL RESET
      CALL SRAND(IX,CX,4)
      ALT=XMAL+EREN(KK)*ZX(1)*COIN(CX(1))
      VEL=XMAS+EREN(KK+NN)*ZX(2)*COIN(CX(2))
      THET=XMDI+EREN(KK+2*NN)*ZX(3)*COIN(CX(3))
      TRST=XMTR+EREN(KK+3*NN)*ZX(4)*COIN(CX(4))
      DT=1.0
      CAS=VEL*((-.1407E-04*ALT)+1.0)+5.0
      CALL SAMP(VEL,CAS,THET,FLAG,ALT,.FALSE.,MIL,MILS,
     1ERROR)
      CALL SNORM(IX,EREAD,2)
      CALL SRAND(IX,CRX,2)
         DO 50 K=1,30
         SPL=VEL
```

```
         ALTL=ALT
         CALL  INTEG(VEL,DT,ALT)
         IF ( ALT .LT. (ERROR(9)-10.)) GO TO 40
         CAS=VEL*((-.1407E-04*ALT)+1.)+5.
         TAS=TRUN4(VEL+COIN(CRX(1))*EREAD(1)*.5)
         ALTI=TRUNC(ALT+COIN(CRX(2))*EREAD(2)*10.)
         CALL  SAMP(TAS,CAS,THET,FLAG,ALTI,.TRUE.,MIL,
     1   MILS,ERROR)
         IF (FLAG) CALL  ADTHET(TAS,THET,THETO,ALT,MIL)
         IF( ABS(ALT-ERROR(9)) .LE. 10.) GO TO 60
         GO TO 50
 40      DT=DT*(ALTL-ERROR(9))/(ALTL-ALT)
         ALT=ALTL
         VEL=SPL
 50      CONTINUE
 60   ALTR=ALT
      VELR=VEL
      THETA=THET +.0572958*FLOAT(MIL)
      THET=THETA
      CALL  TRAJ(VEL,THETA,VE,ALT,DRT)
      MILSC=MIL+IFIX(1000.*(ATAN(ALTR/DRT)-THETA*.0174533))
      EMILS(KK)=FLOAT(MILS-MILSC)
      DRTC=ALTR/TAN(.0174533*THETA+.001*FLOAT(MILS-MIL))
      EDRT(KK)=DRTC-DRT
      THET=THETO
      CALL  TRAJ(VELR,THET,VE,ALTR,DRTU)
      DRTA=ERROR(9)/TAN(THET*.0174533+.001*(ERROR(10)-
     1FLOAT(MIL)))
      EDRTU(KK)=DRTU-DRTA
      PER(KK)=EDRT(KK)/EDRTU(KK)
      IF( PER(KK) .LT. -1.0) PER(KK)=-1.1
      IF( PER(KK) .GT. 1.0) PER(KK)=1.1
300   CONTINUE
      CALL  HISTG(EMILS,NN,0)
      WRITE(6,101)
      WRITE(6,5)(ERROR(I),I=7,9)
      CALL  HISTG(EDRT,NN,0)
      WRITE(6,102)
      WRITE(6,5)(ERROR(I),I=7,9)
      CALL  HISTG(EDRTU,NN,0)
      WRITE(6,103)
      WRITE(6,5)(ERROR(I),I=7,9)
      CALL  HISTG(PER,NN,0)
      WRITE(6,104)
      WRITE(6,5)(ERROR(I),I=7,9)
310   CONTINUE
      STOP
      END
```

```
      SUBROUTINE RESET
      I=0
      RETURN
      ENTRY ADTHET(DX,THET,THETO,ALT,MIL)
      IF (I .GT. 0) GO TO 10
      THETO=THET
      I=1
   10 DIVE=THET*.0174533+.001*FLOAT(MIL)
      X=ALT/TAN(DIVE)
      DIVEN=ATAN(ALT/(X+DX))
      THET=57.2958*(DIVEN-.001*FLOAT(MIL))
      RETURN
      END
      SUBROUTINE TRAJ(TAS,THXT,VE,ALT,ZZ)
      DIMENSION VX(2),VY(2),X(2),Y(2)
      F1(Y,V,VX)=-DRIG(V,Y)*VX
      F2(Y,V,VY)=-DRIG(V,Y)*VY-32.17
      DT=1.0
      XM=260./32.17
      VAC=TAS*1.689
      VB=SQRT(VE**2+VAC**2)
      THET=THXT*.01745
      PHI=THET+ATAN(VE/VAC)
      VX(1)=VB*COS(PHI)
      VY(1)=-VB*SIN(PHI)
      Y(1)=ALT+18.*SIN(THET)-7.*COS(THET)
      X(1)=-(18.*COS(THET)+7.*SIN(THET))
   10 CONTINUE
      VX1=F1(Y(1),VB,VX(1))  *DT
      VY1=F2(Y(1),VB,VY(1)) *DT
      X1=VX(1) *DT
      Y1=VY(1) *DT
      VEL=SQRT((VX(1)+.5*VX1)**2+(VY(1)+.5*VY1)**2)
      YT=Y(1)
      VX2=DT*F1(YT,VEL,.5*VX1+VX(1))
      VY2=DT*F2(YT,VEL,VY(1)+.5*VY1)
      X2=DT*(VX(1)+.5*VX1)
      Y2=DT*(VY(1)+.5*VY1)
      VEL=SQRT((VX(1)+.5*VX2)**2+(VY(1)+.5*VY2)**2)
      VX3=DT*F1(YT,VEL,VX(1)+.5*VX2)
      VY3=DT*F2(YT,VEL,VY(1)+.5*VY2)
      X3=DT*(VX(1)+.5*VX2)
      Y3=DT*(VY(1)+.5*VY2)
      VEL=SQRT((VX(1)+VX3)**2+(VY(1)+VY3)**2)
      VX4=DT*F1(YT,VEL,VX(1)+VX3)
      VY4=DT*F2(YT,VEL,VY(1)+VY3)
      X4=DT*(VX(1)+VX3)
      Y4=DT*(VY(1)+VY3)
```

```
      X(2)=X(1)+.166667*(X1+2.*X2+2.*X3+X4)
      Y(2)=Y(1)+.166667*(Y1+2.*Y2+2.*Y3+Y4)
      VY(2)=VY(1)+.1666667*(VY1+2.*VY2+2.*VY3+VY4)
      VX(2)=VX(1)+.1666667*(VX1+2.*VX2+2.*VX3+VX4)
      IF(Y(2))40,50,60
   40 IF (Y(2) .GT. -5.) GO TO 50
      DT=DT*Y(1)/(Y(1)-Y(2))
      GO TO 10
   50 CONTINUE
      ZZ=X(2)
      RETURN
   60 IF(Y(2).LT.5.) GO TO 50
      TIME=TIME+DT
      VX(1)=VX(2)
      X(1)=X(2)
      VY(1)=VY(2)
      Y(1)=Y(2)
      VB=SQRT(VY(1)**2+VX(1)**2)
      GO TO 10
      END
      FUNCTION DRIG(VB,Y)
      DIMENSION CD(7),XMN(7),VS(7)
      DATA CD/.0805,.0805,.0872,.0991,.1421,.2327,.2446/
      DATA XMN/.0 ,.810,.870,.90,.960,1.05,1.09/
      DATA VS/661.7,659.5,657.2,654.9,652.6,650.3,647.9/
      AY=Y/1000.
      I=IFIX(AY)
      X=AY-FLOAT(I)
      ASS=(VS(I+1)-VS(I))*X+VS(I+1)
      AMN=VB/(ASS*1.689)
      I=2
   10 IF(AMN .LT. XMN(I)) GO TO 20
      I=I+1
      IF(I .GT. 7) GO TO 15
      GO TO 10
   15 WRITE(6,101)
  101 FORMAT(1H0,'XMN TOO BIG')
      DRIG=0.0
      RETURN
   20 AKD=CD(I-1)+((CD(I)-CD(I-1))/(XMN(I)-XMN(I-1)))*(AMN-XMN(I-1))
      DRIG=1.62555E-04*EXP(.00003158*Y)*VB*AKD
      RETURN
      END
```

```
      SUBROUTINE SAMP(TS,CAS,THAT,SWIT,HT,SHFT,MIL,MILS,ERRAR)
      DIMENSION ERRAR(10)
      DIMENSION ERROR(10),ALT(3),TAS(3),FX(2)
      DATA T1/4.0/
      LCGICAL SWIT
      LCGICAL SHFT
      T(X)=-164.415 + X*(.8121744-X*.6827249E-03)
      B(X)= 79.67641 + X*(.1399574-X*.7575896E-02)
      MIL=-COS(THAT*.0174533)*(T(CAS)-B(THAT))
      DX=0.0
      SWIT=.FALSE.
      THET=THAT+FLOAT(MIL)*.057295
      IF(SHFT) GO TO 30
      DO 1 I=1,10
    1 ERROR(I)=ERRAR(I)
      ALT1=SIN(ERROR(7)*.01745)*ERROR(8)*1.689*T1+ERROR(9)
      DIVL= ERROR(7)
      SPED= ERROR(8)
      K= 0
      STIP= ERROR(3)/ERROR(6)
      SHAL= ERROR(4)/ERROR(5)
      FAST= ERROR(1)/ERROR(6)
      SLOW= ERROR(2)/ERROR(5)
      MILS=IFIX(ERROR(10))
      NIL=MIL
      RETURN
   30 CCNTINUE
      THAT=THAT+FLOAT(NIL-MIL)*.0572958
      NIL=MIL
      IF(HT.LT.ALT1) RETURN
      K=K+1
      IF (K .EQ. 3) MILS=IFIX(ERROR(10))
      IF(THET-DIVL) 10,100,20
   10 MILS=MILS+(DIVL-THET)*SHAL
      DX=ERROR(4)*(DIVL-THET)
      GO TO 100
   20 MILS=MILS+(DIVL-THET)*STIP
      DX=ERROR(3)*(DIVL-THET)
  100 DIVL=THET
      GO TO (110,120,130),K
  110 ALT(1)=HT
      TAS(1)= TS
      P2= TS
      RETURN
  120 TAS(2)=TS
```

```
      ALT(2)=HT
      FX(2)=(TAS(2)-TAS(1))/(ALT(2)-ALT(1))
      P2=P2+FX(2)*(ERROR(9)-ALT(1))
      DIVL=ERROR(7)
      RETURN
  130 P2=P2+(((TS-TAS(2))/(HT-ALT(2))-FX(2))/(HT-ALT(1)))*(ERROR(9)-
     1ALT(1))*(ERROR(9)-ALT(2))
      K=0
      SWIT=.TRUE.
      IF(IFIX(P2)-IFIX(SPED))140,160,150
  140 MILS=MILS+SLOW*(SPED-P2)
      TS=DX+(SPED-P2)*ERROR(2)
      GO TO 160
  150 MILS=MILS+FAST*(SPED-P2)
      TS=DX+(SPED-P2)*ERROR(1)
  160 CONTINUE
      RETURN
      END
//GO.FT06F001 DD SYSOUT=D
//GO.SYSIN DD *
    -7.32500E00
     5.41608E01
   -3.93751E-02
    -9.46706E00
     5.33395E01
   -3.81394E-02
    -1.57772E01
     5.14052E01
   -3.44066E-02
    -3.14242E01
     4.99344E01
   -2.90602E-02
     1.34523E01
     6.46076E01
   -5.73131E-02
    -9.46034E01
     4.06686E01
   -1.03355E-02
 23547851
 3.7
   3.8
   35.
   41.
    9.7
    9.9
    20.
  450.
  2000.
```

135.			
5500.	396.	20.	10000.
3.2			
3.3			
26.			
30.			
8.3			
8.4			
30.			
450.			
3000.			
135.			
6000.	345.	28.6	20000.
5.2			
5.4			
49.			
55.			
13.			
13.			
30.			
500.			
5000.			
156.			
9000.	400.	30.	20000.
2.1			
2.2			
17.			
19.			
6.7			
6.7			
45.			
450.			
4000.			
105.			
8000.	370.	45.	2500.
3.1			
3.2			
29.			
32.			
9.8			
9.9			
45.			
500.			
6000.			
116.			
10400.	400.	45.	4000.
1.9			
2.0			

23.			
24.			
8.6			
8.6			
60.			
500.			
7000.			
77.			
13000.	380.	60.	4000.

APPENDIX G

PLM AIR TO GROUND PROGRAM

```
        /* COS  IN  HEX */  DECLARE COS(23) ADDRESS INITIAL
       (200H,1FFH,1FEH,1F5H,1ECH,1E1H,1D4H,1C4H,1B2H,19EH,
        188H,171H,157H,13BH,11FH,100H,0E1H,0C0H,09EH,07CH,
        059H,036H,012H);
        /* DCOS IN HEX */ DECLARE DCOS(23) ADDRESS INITIAL
        (2,7,12,11H,16H,1BH,1FH,24H,27H,2CH,30H,33H,37H,
        3AH,3DH,3FH,41H,43H,45H,46H,47H,47H,48H);
        DECLARE  B(22) BYTE INITIAL (80,80,80,79,79,78,78,
        77,76,75,74,72,69,67,64,60,57,53,49,45,41,37);
DECLARE DITA (6) ADDRESS INITIAL(345,6000,357,5703,369,5394);
DECLARE PERIOD BYTE INITIAL(250);
DECLARE(TAS,ALT) ADDRESS;
 DECLARE TABLE (192) ADDRESS INITIAL(080,0,0,0,0,0,0,0,0,
 0,0,0,0,0,0,0,27Q,31Q,30Q,34Q,2000,450,135,20,
  30Q,31Q,31Q,35Q,3000,450,133,30,0,0);
/* HERE THE INITIAL VALUES ARE ASSIGNED  */
DECLARE (WEAPON, DELIV,BASE) BYTE;
DECLARE (FAST, SLOW, STIP, SHAL, RELALT, RELAS,
        RELMIL, RELDIV,BA) ADDRESS ;
DECLARE (CAS,      THET) BYTE;
DECLARE (FTS,FALT, X0,X1,X2,F0,F1,F2,F10,F21,F210,FX) (3)
  BYTE, K BYTE;
DECLARE(DUM1,DUM2,T1,T2,X,MF10)(3) BYTE;
SET$UP: PROCEDURE ;
  BASE = SHL(WEAPON,6) + SHL(DELIV,3);
  FAST = TABLE(BASE);
  SLOW = TABLE(BASE + 1);
  STIP = TABLE(BASE + 2);
  SHAL = TABLE(BASE + 3);
  RELALT = TABLE(BASE + 4);
  RELAS  = TABLE(BASE + 5);
  RELMIL = TABLE(BASE + 6);
  RELDIV = TABLE(BASE + 7);
  BA     = B(SHR(RELDIV,2));
END SET$UP;
/* INPUT WEAPON AND DELIV, LABELED LOOP1 */
MIL: PROCEDURE(CS,THT) BYTE ;
DECLARE (CS,THT) BYTE ;
DECLARE (T,CT) ADDRESS ;
  /* T= (174Q +( CS *((3775Q-(CS *123Q)/16)/4)/128)/8  */
  T=SHR(( 174Q + SHR ( CS * SHR(3775Q- SHR(CS *123Q, 4)
  ,2)  ,  7)), 3  );
  CT = COS( SHR(THT ,2))-SHR((THT  AND 3) * DCOS(SHR(THT
     ,2)),1);  /*CT=COS(THET/4)- THET MOD 4 * DCOS  */
  RETURN  SHR(CT *(BA-T),9) ;
END MIL ;
MILS: PROCEDURE BYTE;  DECLARE CM BYTE;
```

```
   THET = THET + SHR( 353Q * MIL(CAS,THET),12);

   IF THET > RELDIV THEN  /* STEEP   */
      CM = RELMIL - SHR( STIP *(THET - RELDIV)+4,3);
      ELSE          /* SHALLOW   */
      CM = RELMIL + SHR( SHAL *(RELMIL -THET)+4,3);
   IF RELDIV = 0 THEN DO;
   /* FOR A LEVEL DELIVERY CORRECT FOR DIVE AND
   CURRENT AIRSPEED */
   IF TAS > RELAS
       THEN DO; /* FAST DECREASE SIGHT ANGLE */
       CM=CM- SHR( FAST*(TAS-RELAS)+32, 6) ;
       RETURN CM;
       END;
   ELSE DO;    /* SLOW   ADD  TO SIGHT */
       CM=CM+SHR( SLOW *(RELAS-TAS) +32,  6 );
       RETURN CM;
       END;
   END;
   DO CASE K ;
   /*  PASS 1 */
   DO;
   /*  X:= RELEASE ALTITUDE  */
   CALL FLOAT(.RELALT,.X);
   /*  FO := TAS;  FO:=-FO  */
   CALL FLOAT(.TAS,.FO);  FO(2)=FO(2) OR  80H;
   /*  XO:= ALT; XO:= -XO */
   CALL FLOAT(.ALT,.XO);  XO(2)=XO(2) OR  80H;
   /*  T1:= X +XO  ( REALLY X- ABS(XO)  ) */
   CALL ADD(.X,.XO,.T1);
A1:
   RETURN  CM ;
   END;
   /* SECOND PASS */
   DO;
   /* F10 = (F1 - FO)/(X1 - XO)  */
   CALL FLOAT(.TAS,.F1);    /* F1 := TAS */
   CALL FLOAT(.ALT,.X1);    /* X1 := ALT */
   /* DUM1:= F1 + FO; ( REALLY F1 - ABS(FO)  )  */
   /*  FO:= -FO  */
   CALL ADD(.F1,.FO,.DUM1);  FO(2) =FO(2) XOR 80H;
A2:
   /*  DUM2  := X1 + XO;  ( X1 - ABS (XO  )  )  */
   CALL ADD(.X1,.XO,.DUM2);
   /*  CALCULATE F10  */
   CALL DIV(.DUM1,.DUM2,.F10);
A3:
   /*  MF10 := -F10  */
```

```
    MF10 = F10;
    MF10(1) =F10(1);
    MF10(2) =F10(2) XOR 80H;
    X1(2) = X1(2) OR 80H ;      /*  X1 := -X1   */
    F1(2) = F1(2) OR 80H;       /*  F1 := - F1  */
    CALL ADD(.X,.X1,.T2);       /* T2 := X+ X1  */
    RETURN CM ;
    END;


    /* PASS 3  */
    DO;
    CALL FLOAT(.TAS,.F2);       /*  F2 := TAS */
    CALL FLOAT(.ALT,.X2);           /* X2 := ALT  */
A4:
    /* F21 = (F2 - F1)/(X2 - X1)  */
    CALL ADD(.F2,.F1,.DUM1);
    CALL ADD(.X2,.X1,.DUM2);
    CALL DIV(.DUM1,.DUM2,.F21);
    /* F210= (F21 - F10)/(X2 - X1) */
    CALL ADD(.F21,.MF10,.DUM1);
    CALL ADD(.X2,.X0,.DUM2);
    CALL DIV(.DUM1,.DUM2,.F210);
    /* FX = F0 +(X-X0)*(F10 +F210*(X -X1))   */
    CALL MUL(.F210,.T2,.DUM1);
A5:
    CALL ADD(.DUM1,.F10,.DUM2);
    CALL MUL(.DUM2,.T1,.DUM1);
    CALL ADD(.DUM1,.F0,.FX);
    CALL FIX(.FX,.TAS);
A6:

    IF TAS > RELAS
      THEN DO;  /* PREDICTED FAST DECREASE SIGHT ANGLE */
      CM=CM- SHR( FAST*(TAS-RELAS)+32, 6);
      RETURN CM;
      END;
      ELSE DO; /* PREDICTED SLOW INCREASE SIGHT ANGLE  */
      CM=CM+ SHR( SLOW*(RELAS-TAS) +32 ,6);
      RETURN CM;
      END;
     END;
    END; /*  END OF CASE K */
   END MILS;
    LOOP1:  WEAPON = 0;
         DELIV=3;
         CALL SET$UP;
    LOOP2: CAS= 100;
```

```
          THET=30;
          K= MIL(CAS,THET);
     LOOP3: THET = 28;
          TAS=DITA;
          ALT=DITA(1);
          K=0;
          DISP=MILS;
      CALL TIME(PERIOD);
      CALL TIME(PERIOD);
     LOOP4: THET=28;
          TAS=DITA(2);
          ALT = DITA(3);
          K=1;
          DISP=MILS;
      CALL TIME(PERIOD);
      CALL TIME(PERIOD);
     LOOP5:  THET=30;
          TAS= DITA(4);
          ALT=DITA(5);
          K=2;
          DISP=MILS;
   EXIT:  HALT;
    EOF
```

APPENDIX H

PLM AIR TO AIR PROGRAM

```
//    EXEC    PLM80CG,REGION.PASS1=150K,REGION.PASS2=150K
//PASS1.CARD  DD  *
$SYMBOLS=1
$R=80
$M=1
     FLOAT: PROCEDURE(INN,FA);
   /* A PROCEDURE TO CONVERT AN INTEGER INN TO
   A FLOATING POINT WHOSE MANTISSA IS FOUND IN
   ADDRESSES  FA AND FA+1  AND WHOSE EXPONENT
   IS IN FA +2  */

   DECLARE (INN,FA) ADDRESS ,MANN ADDRESS,
      MANT BASED FA BYTE,
      INT BASED INN ADDRESS,
      N BYTE;

      IF INT = 0                  /* CHECK FOR ZERO INPUT */

        THEN  DO;
        MANT(2),MANT(1),MANT = 0;
        RETURN ;
        END;

      MANT(2) = 50H;              /* EXPONENT = 2**16  */
      MANN = INT;

      IF ( MANN AND 8000H) = 8000H THEN /* NEGATIVE INTEGER */
        DO;   MANT(2) = MANT(2) OR 80H; /* SET SIGN BIT */
              MANN    = 1-MANN ;        /* COMPLEMENT   */
        END;

      N = 1;         /* NORMALIZE MANTISSA */
      DO WHILE (( SHL(MANN,1) AND 8000H) <> 8000H);
       N=N+1;
       MANN = SHL(MANN,1);
      END;

      MANN= SHL(MANN,1);
      MANT(2) = MANT(2) - N;  /* ADJUST EXPONENT */
      MANT    = HIGH(MANN);   /* ASSIGN MANTISSA */
      MANT(1) = LOW(MANN);
      RETURN ;
   END FLOAT;
   FIX: PROCEDURE(FP,INT);    /* REAL TO POSITIVE INTEGER */
     DECLARE (FP,INT) ADDRESS,
     M BASED FP BYTE, I BASED INT ADDRESS,
     N BYTE ;
```

```
        IF((M(2) AND 80H)=80H) OR ((M(2) AND 40H)=00H)
          THEN DO;     /* NEGATIVE EXPONENT OR MANTISSA */
               I = 0;
               RETURN       ;
               END;

        IF( N:= M(2) AND 3FH)> 15   /* EXPONENT TOO LARGE */
        THEN DO;
          I   = 7FFFH ;            /* RETURN MAXIMUM INTEGER */
          RETURN ;
        END;

         I=M;  I=(SHL(I,8) OR M(1)) +SHL(1,15-N);
        I    = SHR(I  ,(16-N));   /* RIGHT JUSTIFY */
        RETURN ;
      END FIX;
       DECLARE DISP BYTE;  DECLARE ZE BYTE;
       DECLARE ZZ ADDRESS;
      /*  FLOATING POINT DIVIDE ROUTINE */
  DIV:  PROCEDURE (XA,YA,PA);
         DECLARE (XA,YA,ZA,B,XX,YQ) ADDRESS,
          PA ADDRESS,P BASED PA BYTE,
               I BYTE,
               X BASED XA BYTE,
               Y BASED YA BYTE,
             C (3) BYTE;


         XX=SHL(DOUBLE(X),8) OR X(1);
         YQ=SHL(DOUBLE(Y),8) OR Y(1);
          IF XX =0H THEN DO;
            ZZ=0H; ZE=0H; GO TO RET;
          END;
         XX=SHR(XX,1);
         YQ=SHR(YQ,1);
   ENTO: ZZ=0;
         C(2)=    X(2);
            I=1;
         B=XX-YQ;
         IF NOT CARRY THEN DO;
                     IF B=0 THEN DO;
                       ZZ=8000H;
                       ZE=(((    X(2) AND 80H) XOR (    Y(2) AND 80H))
                        OR ((C(2) AND 7FH)-(    Y(2) AND 7FH)+65));
                        GO TO RET;
                      END;
```

```
            GOTO ENT2;
            END;
        XX=SHL(XX,1);
        C(2)=    (C(2) AND 7FH) - 1;
ENT1:   B=XX-YQ;
        IF CARRY THEN DO;
            XX=SHL(XX,1);
            GOTO ENT3;
            END;
 /* NO CARRY, ADD ONE TO DIVIDEND TO MANTISSA AND SHIFT LEFT */
ENT2:   XX=SHL(B,1);
        ZZ=ZZ+1;
 /* CARRY SHIFT DIVIDEND MANTISSA LEFT */
ENT3:   ZZ=SHL(ZZ,1);
        I=I+1;
        IF I< 16 THEN GOTO ENT1;
 /* SET EXPONENT */
          ZE=(((    X(2) AND 80H) XOR (    Y(2) AND 80H)) OR
                   ((C(2) AND 7FH) - (    Y(2) AND 7FH)+65));
 RET:     P=HIGH(ZZ);P(1)= LOW(ZZ);P(2)=ZE;
          RETURN;
END DIV;
 /* FLOATING POINT MULTIPLY ROUTINE */
MUL: PROCEDURE(XA,YA,PA);
       DECLARE
       XA ADDRESS, X BASED XA BYTE,
       YA ADDRESS, Y BASED YA BYTE,
       PA ADDRESS,P BASED PA BYTE,
       TQ ADDRESS;
       IF (X=0) OR (Y=0) THEN DO; ZZ=0; ZE=0; GO TO RET;  END;
       ZZ=X(1)*Y(1);
       ZZ=X(1)*Y+HIGH(ZZ);
       TQ=X*Y(1)+ZZ;
       IF CARRY THEN ZZ=X*Y+256+HIGH(TQ);
       ELSE ZZ=X*Y+HIGH(TQ);
          IF LOW(TQ)>=80H THEN ZZ=ZZ+1;
          IF ZZ<8000H THEN DO; ZZ=SHL(ZZ,1);  ZE=-1;
              IF LOW(TQ)>=0C0H THEN ZZ=ZZ+1;
         END;
       ELSE ZE=0;
      /* ADD EXPONENTS   */
       ZE=((X(2) AND 7FH) +(Y(2) AND 7FH)-64 +ZE) OR((X(2) AND 80H)
                                              XOR ( Y(2) AND 80H));
 RET:     P=HIGH(ZZ);P(1)= LOW(ZZ);P(2)=ZE;
           RETURN;
END MUL;
 /* FLOATING POINT ADD ROUTINE*/
ADD: PROCEDURE (XA,YA,PA);
```

```
   DECLARE (XA,YA,ZA) ADDRESS,
     PA ADDRESS, P BASED PA BYTE,
           (I,R2,Y2,DIGIT,SINE) BYTE,
           X BASED XA BYTE,
           Y BASED YA BYTE,
            (XX,YQ) ADDRESS;


/* PROCEDURE TO LEFT JUSTIFY MANTISSA IN BINARY */
  ADJUST: PROCEDURE;
    DO I=0 TO 15;
       IF (ZZ AND 8000H)=8000H THEN RETURN;
      ZZ=SHL(ZZ,1);
      ZE=ZE-1;
   END;    RETURN;
    END ADJUST;

   XX=SHL(DOUBLE(X),8) OR X(1);
   YQ=SHL(DOUBLE(Y),8) OR Y(1);
   R2=       X(2) AND 7FH;
   Y2=       Y(2) AND 7FH;
   DIGIT=R2-Y2;
    SINE =(X(2) AND 80H) XOR (Y(2) AND 80H);
    IF (DIGIT AND 80H)<>0     THEN DIGIT=-DIGIT;
   IF DIGIT >= 16  THEN DO;
/* VARIABLES NOT WITHIN SIGNIFICANCE RANGE */
    IF R2 > Y2 THEN DO;
     ZZ=XX; ZE=X(2); GO TO RET;
      END;
     ZZ=YQ; ZE=Y(2); GO TO RET;
      END;
    IF Y2 = R2 THEN DO;
/* EXPONENTS EQUAL IN ABSOLUTE VALUE      */
          IF YQ>XX THEN DO;
/* Y > X */
             ZE= Y(2);
              IF SINE < 80H THEN GO TO EXIT1;
                         GO TO EXIT2;
                  END;
         IF YQ<XX THEN DO;
/* X > Y */
                  ZE =X(2);
              IF SINE < 80H THEN GO TO EXIT1;
      GO TO EXIT3;
                  END;
/* X = Y */
              IF SINE < 80H THEN DO;
     ZE=X(2);        GO TO EXIT1;        END;
```

```
                ZZ=0;
                    ZE     = 0;
                GO TO RET;
                     END;
    IF Y2 > R2 THEN DO;
 /* Y > X */
               ZE    =      Y(2);
         XX=SHR(XX,DIGIT);
                IF SINE < 80H THEN GO TO EXIT1;
                            GO TO EXIT2;
                     END;
 /* X > Y */
               ZE    =      X(2);
         YQ=SHR(YQ,DIGIT);
                IF SINE < 80H THEN GO TO EXIT1;
       GO TO EXIT3;
    EXIT1:
     ZZ=XX+YQ;
     IF CARRY THEN DO;
         ZZ=SCR(ZZ,1);
         ZE=ZE  +1;
    END;
          GO TO RET;
        EXIT2:
                ZZ=YQ-XX;
                CALL ADJUST;
        GO TO RET;
     EXIT3:
                ZZ=XX-YQ;
                CALL ADJUST;
 RET:  P=HIGH(ZZ);P(1)= LOW(ZZ);P(2)=ZE;
      RETURN;
END ADD;
   SUB: PROCEDURE(FIRST,SECOND,THIRD);
  DECLARE (FIRST,SECOND,THIRD) ADDRESS, X BASED SECOND
    BYTE;
    X(2)=X(2) XOR 80H;
    CALL ADD(FIRST,SECOND,THIRD);
   RETURN;
   END SUB;
   MULT: PROCEDURE(X,Y,Z);
   DECLARE (X,Y,Z) ADDRESS;
    CALL MUL(X,Y,Z);
RETURN;
   END MULT;
COMPARE: PROCEDURE (XA,YA) BYTE;

  /* ROUTINE TO COMPARE TWO FLOATING POINT VARIABLES */
```

```
    /*     IF X<Y COMPARE=0
           X=Y COMPARE=1
         X>Y COMPARE=2     */
   DECLARE (XE,YE) BYTE;
     DECLARE X BASED XA BYTE,
             Y BASED YA BYTE,
             (XA,YA,CHECK1,CHECK2) ADDRESS,
             (XP,YP) BYTE;

  /* EQUAL EXPONENTS */
       XE=X(2) AND 80H;
       YE=Y(2) AND 80H;
         IF ( XE=YE ) THEN DO;
             XP=X(2) AND 7FH;
             YP=Y(2) AND 7FH;
          CHECK1=SHL(DOUBLE(X),8) OR X(1);
          CHECK2=SHL(DOUBLE(Y),8) OR Y(1);
             IF ( XE=80H ) THEN DO;
                IF ( XP<YP ) THEN RETURN 2;
                 IF (XP > YP ) THEN RETURN 0;
                   IF CHECK2 < CHECK1 THEN RETURN 0;
                   IF CHECK2 > CHECK1 THEN RETURN 2;
                   RETURN 1;
             END;
             IF ( XP < YP ) THEN RETURN 0;
               IF ( XP > YP ) THEN RETURN 2;
          IF CHECK2 < CHECK1 THEN RETURN 2;
          IF CHECK2 > CHECK1 THEN RETURN 0;
          RETURN 1;
          END;
           IF ( XE = 0 ) THEN RETURN 2;
            RETURN 0;
END COMPARE;
DECLARE        (ID,TEMP,TEMP1,TEMP2,ENTRY,ENTRY1,ENTRY2) BYTE;
    FUNCTION: PROCEDURE(I,XA);
  /* .I=0      CDTABLE
      I=1      ATMOSPHERE
      I=2      COSINE
      I=3      ATAN1
      I=4 ATAN2    */
       DECLARE (E,V,D,V1,D1) (3) ADDRESS  INITIAL(
       3000H,3300H, 2D77H,
       3100H,3387H,2F3AH,
       3200H,346EH,2EFDH,
0000H,3525H,0000H,
       0000H,35DCH, 0000H),
          I BYTE,
      LOOK (3) BYTE INITIAL (252,181,192),
```

```
MAX (3)    BYTE INITIAL (252,181,192),
  ENTA ADDRESS,ENT BASED ENTA BYTE,
   VALA ADDRESS,VAL BASED VALA BYTE,
  DIFFA ADDRESS,DIFF BASED DIFFA BYTE,
  VAL1A ADDRESS, VAL1 BASED VAL1A BYTE,
  (LOOKI,MAXI) BYTE,
  DIFF1A ADDRESS,DIFF1 BASED DIFF1A BYTE;
 /*  INPUT  CONSISTS OF A BASED VARIABLE,  OUTPUT WILL BE
     IN GLOBAL VARIABLES T, T1, T2.  AND Z, Z1, Z2,
        FOR RHO AND INVS RESPECTIVELY     */
 DECLARE XA ADDRESS, X BASED XA BYTE;

  ENTA=E(I);  VALA=V(I);     DIFFA=D(I);
  VAL1A=V1(I);    DIFF1A=D1(I);
 LCCKI=LOOK(I);
  MAXI=MAX(I);
 ENTRY=X; ENTRY1=X(1); ENTRY2=X(2);
 IF(LOOKI=MAXI) THEN LOOKI=0;
 ID=COMPARE(.ENTRY,ENTA+LOOKI);
      IF(ID=1) THEN GOTO EXIT1;
 /*   READ UPWARDS IN THE TABLE*/
       IF(ID>1) THEN DO;
LOOP1:    IF (LOOKI=MAXI) THEN GO TO EXIT1;
           LOOKI=LOOKI+3;
 ID=COMPARE(.ENTRY,ENTA+LOOKI);
             IF(ID=1) THEN GO TO EXIT1;
               IF(ID>1) THEN GO TO LOOP1;
        LOOKI=LOOKI-3;  GO TO EXIT2;
        END;
  /*   READ DOWNWARDS IN THE TABLE    */
LOOP2:    IF(LOOKI=0) THEN GO TO EXIT1;
        LOOKI=LOOKI-3;
  ID=COMPARE(.ENTRY,ENTA+LOOKI);
              IF(ID=1) THEN GO TO EXIT1;
                IF(ID<1) THEN GOTO LOOP2;
                 GOTO EXIT2;

EXIT1:  T=VAL(LOOKI);  T1=VAL(LOOKI+1);  T2= VAL(LOOKI+2);
   IF I<>1 THEN GO TO RET;
 Z=VAL1(LOOKI);  Z1=VAL1(LOOKI+1);   Z2=VAL1(LOOKI+2);  GO TO RET;

 EXIT2:  TEMP=ENT(LOOKI);  TEMP1=ENT(LOOKI+1);  TEMP2=ENT(LOOKI+2);
   /*   CHANGE THE SIGN OF TEMP     */
        TEMP2=TEMP2 XOR 80H;
  /*    ENTRY - ENT(LOOK)   */
        CALL ADD(.TEMP,.ENTRY,.TEMP);

   /*  (ENTRY - ENT(LOOK))* DIFF(LOOK)     */
```

```
      CALL MULT(.TEMP,DIFFA+LOOKI,.T);
      CALL ADD(.T,VALA+LOOKI,.T);
      /*  VAL(LOOK)+ENTRY-ENT(LOOK) *DIFF(LOCK)     */
   IF I<>1 THEN GO TO RET;
       CALL MULT(.TEMP,DIFF1A+LOOKI,.Z);
     CALL ADD(.Z,VAL1A+LOOKI,.Z);
   RET: LOOK(I)=LOOKI;
       RETURN;
  END FUNCTION;
  DECLARE (T,T1,T2,Z,Z1,Z2) BYTE; /* COS AND SIN */
 CCSSIN: PROCEDURE(XA);
    /*  THIS ROUTINE  COMPUTES  BOTH  THE  SINE  AND
        THE  COSINE  FOR  THE  GIVEN  ANGLE  XA  IN
         RADIANS .  THE  OUTPUT    VALUES  ARE
         STORED  IN  GLOBAL  VARIABLES  Z,Z1,Z2
         FOR      COSINE   T,T1,T2  FOR SINE  */
     DECLARE  (TH,TH1,TH2,THN,THN1,THN2,TMP,TMP1,TMP2) BYTE,
     (MPI2,MPI21,MPI22)    BYTE  INITIAL (OC9H,OFH,OC1H) ,
               XA  ADDRESS , X BASED  XA  BYTE;
    TH=X; TH1=X(1); TH2=X(2);
     DECLARE OUT LABEL;
     DECLARE I BYTE;
     DO I=1 TO 4;
     THN=TH;  THN1=TH1 ; THN2=TH2;
     CALL ADD (.TH,.MPI2,.TH);/*THETA - PI2 */
               /*  THN IS THBAR AND TH IS THBAR - PI/2   */
     IF(ZE AND 80H) <> 0 THEN GO TO OUT;
     END;
     RETURN;
   OUT:
        TH2=ZE AND 7FH;
     CALL FUNCTION (2,.THN);
     THN=T ;  THN1=T1;  THN2=T2;
  /* THN= COS (TH )   */
     CALL FUNCTION (2,.TH);
    /*   TH= COS PI/2-TH)       */
     TH=T;    TH1=T1; TH2=T2;
     IF ((I=1)OR (I=3)) THEN DO;
           Z=THN; Z1=THN1 ;Z2=THN2;
           T=TH;  T1=TH1 ;  T2=TH2;
           IF(I=3) THEN DO;
              Z2=Z2 XOR 80H;
              T2=T2 XOR 80H;
              RETURN;
              END;
           RETURN;
           END   ;
      Z=TH;  Z1=TH1; Z2=TH2 XOR 80H;
```

```
      T=THN;   T1=THN1; T2=THN2 ;
      IF (I=4) THEN DO;
                 T2=T2 XOR 80H;
                 Z2=Z2 XOR 80H;
                 END;
      RETURN;
  END COSSIN;
     SQRT:  PROCEDURE (XA,PA);
     /*  ASSUME THAT XA IS A POSITIVE REAL NUMBER  */
      DECLARE XA ADDRESS, X BASED XA BYTE;
      DECLARE PA ADDRESS, P BASED PA BYTE;
      DECLARE (C,C1,C2,C3,B,B1,B2) BYTE;
     /* INITIAL APPROXIMATION FOR THE ROOT IS
             MANT * EXP/2  */
      DECLARE R BYTE;
      B=X;  B1= X(1);
       B2=X(2)-64; IF  (B2 AND 80H) =0 THEN B2=SHR(B2,1)+64;
                       ELSE DO; B2=-B2; B2=SHR(B2,1); B2=64-B2;
                             END;
     DO R= 1 TO 4;
           CALL DIV(XA,.B,.C);
          CALL ADD(.C,.B,.B);
           B(2)=B(2)-1;
      END;
     P=B; P(1)=B(1);  P(2)=B(2);
        RETURN;
     END SQRT;
   DECLARE COUNT BYTE INITIAL (0);
LN: PROCEDURE(ARG,VAL);
/*  A PROCEDURE TO CALCULATE THE VALUE OF LN(ABS(X)),
 IF X = 0 THEN THE MAXIMUM NEGATIVE VALUE IS RETURNED.
 REFERENCE  KNUTH, FUNDAMENTAL ALGORITHMS VOL 1 P. 26 */
 DECLARE ( ARG,VAL) ADDRESS, /* ARGUMENT AND ANSWER
  ADDRESSES */
 X BASED ARG BYTE, Y BASED VAL BYTE, Z(3) BYTE, K BYTE;
   DECLARE XE ADDRESS;
  DECLARE (XA,ZA) ADDRESS, CONS(36) BYTE  INITIAL(
 /*  VALUES OF LN(2**K/(2**K-1)) FOR K=0,...,8 */
  0B1H,  72H,40H,  /* LN(2)*/
  93H,4BH,3FH,  /* LN(4/3) */
  88H,0BCH,3EH,  /*  LN(8/7) */
  84H,02DH,3DH,  /* LN(16/15)  */
  82H,0BH,3CH,  /* LN(32/31)  */
  81H,03H,3BH,  /* LN(64/63) */
  80H,7FH,3AH,  /* LN(128/127)  */
  80H,3FH,39H  /*  LN(256/255)  */
 ,80H,1FH,38H  /* LN(512/511) */
  ,80H,10H,37H, /* LN(1024/1023) */
```

```
 0FFH,0F0H,35H, /* LN(2048/2047) */
 0FFH,0F8H,34H /* LN(4096/4095 */
  );
/* CHECK FOR  A ZERO ARGUMENT */
  IF X= 0 THEN DO  ;
   Y=0FFH; Y(1)=0FFH;Y(2)=0FFH; RETURN; END;
 /* ARG := ABS ARG */
  XE=(DOUBLE(X(2)) AND 7FH) -41H;
 CALL FLOAT(.XE,.Z);
  CALL MUL(.Z,.CONS, VAL);
  XA=X; XA=SHL(XA,8 ); XA= XA OR X(1);
   K=1;
   ZA=SHR(XA,1);
  DO WHILE(( XA <> 8000H ) AND ( XA > ZA ));
  IF ( XA < (ZA OR 8000H)) THEN /* XA-ZA < 1 */
  DO;
 ZA= SHR(ZA,1);
  IF ( K= 13) THEN DO; COUNT = COUNT+1;
  RETURN;  END;
  K=K+1;
 END;
  ELSE
 DO;       XA=XA-ZA;
  /* Y = Y + LN(2**K/(2**K-1)) */
  CALL ADD(VAL,.CONS(3*(K-1)),.Z);
        Y=Z; Y(1)=Z(1); Y(2)=Z(2);
        ZA= SHR(XA,K);
   END;
 END /* END OF DO WHILE */  ;
 RETURN;
 END LN;
  SAMP: PROCEDURE;
   DECLARE (TAS,RATE) ADDRESS, CSSW BYTE;
  DECLARE AGF (3) BYTE;
  DECLARE THOU(3) BYTE INITIAL(0FAH,00H,4AH);
   DECLARE
  (AZR,PR,TOTR,SINP,COSP,K,VM) (3) BYTE,
   ALT ADDRESS,
  THET(3) BYTE, (L,SHFT,TD,PL)(3) BYTE,
  (PLEAD,ALEAD) BYTE;
  DECLARE RANGE(3) BYTE;
  DECLARE (VF,VC)(3)BYTE;
  DECLARE RHO(78) BYTE INITIAL(
   /* ALTITUDE      RHO   */
  /* 0 */   99H,0E1H,3DH,
  /*2048*/ 90H,3EH,3DH,
  /*4096*/ 87H,35H,3DH,
  /*6144*/ 0FDH,7BH,3CH,
```

```
 /*8192*/ OEDH,9BH,3CH,
/*10240*/  ODEH,OBAH,3CH,
/*12288*/ ODOH,OC7H,3CH,
/*14336*/ OC3H,OB3H,3CH,
/* 16384*/ OB7H,72H,3CH,
/*18432*/OABH,OF5H,3CH,
/*20480*/OA1H,30H,3CH,
/*22528*/97H,17H,3CH,
/*24576*/8DH,OA1H,3CH,
/* 26624*/ 84H,OC2H,3CH,
/*28672*/ OF8H,OE3H,3BH,
/*30720*/ OE9H,4DH,3BH,
/*32768*/ODAH,OB1H,3BH,
/*34816*/ OCCH,OFEH,3BH,
/*36864*/ OCOH,48H,3BH,
/*38912*/ OB4H,1FH,3BH,
/*40960*/ OA8H,OD7H,3BH,
/*43008*/9EH,44H,3BH,
/*45056*/ 94H,5AH,3BH,
/*47104*/ 8BH,20H,3BH,
/*51200*/ OF4H,61H,3AH)   ,
KDP (3) BYTE INITIAL(OBOH,98H,38H),
  FPS (3) BYTE INITIAL(OD8H,31H,41H),
  GDIV2 (3) BYTE INITIAL( 80H,OAEH,45H),
(TEMP1,TEMP2,TEMP3,TEMP4,TEMP5,TEMP6,TEMP7,TEMP8,
 TEMP9,TEMP10,TEMP11,TEMP12,TEMP13,TEMP14,TEMP15,TEMP16,
TEMP17,TEMP18,TEMP19,TEMP20) (3) BYTE;
DECLARE ONE(3) BYTE INITIAL(80H,OOH,41H);
DECLARE DUM (3) BYTE INITIAL(8FH,OCEH,4CH);
DECLARE KONS(3) BYTE;
GUNS: PROCEDURE;
CALL ADD(.TEMP1,DUM,.VM); /* VM=3300+VF*1.689 */
 CALL MUL(.VM,.KONS,.TEMP1);  /* TEMP1=VM*KONS*/
CALL ADD(.TEMP1,.ONE,.TEMP2); /* TEMP2=TEMP1+1 */
CALL SUB(.VF,.VC,.TEMP3);
CALL LN(.TEMP2,.TEMP4); /* TEMP4=LN(VM*KONS+1)*/
CALL DIV(.TEMP4,.KONS,.TEMP5); /* LN(VM*KONS+1)/KONS*/
CALL ADD(.TEMP3,.RANGE,.TEMP8); /* RANGE +(VF-VC) */
CALL SUB(.TEMP8,.TEMP5,.TEMP9); /* F(1.0) */
CALL DIV(.VM,.TEMP2,.TEMP10); /*VM/(VM*KONS +1) */
CALL SUB(.TEMP3,.TEMP10,.TEMP11); /*F'(1.0) */
CALL DIV(.TEMP9,.TEMP11,.TEMP12); /* F(T)/F'(T) */
 CALL SUB(.ONE,.TEMP12,.TEMP13);  /* TIME OF FLIGHT */
CALL MUL(.TEMP1,.TEMP13,.TEMP14);
CALL ADD( .ONE,.TEMP14,.TEMP15); /* VM*KONS*TIME +1 */
CALL LN(.TEMP15,.TEMP16);     /* LN(VM*KONS*TIME +1) */
CALL MUL(.KONS,.TEMP13,.TEMP17);  /* KONS*TIME */
CALL DIV(.TEMP16,.TEMP17,.TEMP18); /* AVERAGE VELOCITY
```

```
TAKFN AS LN(VM*KONS*TIME+1)/KONS*TIME */
CALL MUL(.TEMP13,.TEMP13,.TEMP16); /* TIME**2 */
CALL MUL(.TEMP16,.THOU,.TEMP17);  /* TIME**2 *1000 */
CALL MUL(.TEMP13,.TEMP18,.TEMP4); /* RANGE TO IMPACT*/
CALL MUL(.GDIV2,.TEMP17,.TEMP19); /* GRAVITY DROP */
CALL DIV(.TEMP19,.TEMP4,.TEMP20); /* MILS GRAVITY DROP*/
CALL DIV(.VF,.VM,.TEMP1);
 CALL MUL(.TEMP1,.AGF,.SHFT); /* LEAD FOR TRAJECTORY
     SHIFT  */
CALL MUL(.TOTR,.RANGE,.TEMP2); /*TGT MOTION NORMAL */
CALL DIV(.TEMP2,.TEMP18,.TEMP3); /* LEAD FOR TGT MOTION
*/
/* LEAD IN PITCH = LEAD FOR TGT MOTION *
(SINP*COS(THET)+COSP*SIN(THET))+TRAJECTORY SHIFT
+3.5+GRAVITY DROP*COS(THET)      */
CALL MUL(.T,.COSP,.TEMP4); /* SIN(THET)*COSP */
CALL MUL(.Z,.SINP,.TEMP5);  /* COS(THET)*SINP */
CALL ADD(.TEMP4,.TEMP5,.TEMP6);
 CALL MUL(.TEMP3,.TEMP6,.TEMP7);  /* L*SIN(THET+PHI) */
CALL ADD(.TEMP7, .SHFT,.TEMP4);
CALL MUL(.Z,.TEMP20,.TEMP7);  /* GRAVITY DROP */
CALL ADD(.TEMP4,.TEMP7,.TEMP5);
CALL FIX(.TEMP5,.PLEAD);
PLEAD=PLEAD+4;   /* PITCH LEAD */
CALL MUL(.Z,.COSP,.TEMP1); /* COS(THET)*COS(PHI) */
CALL MUL(.SINP,.T,.TEMP2);
TEMP2(2)=TEMP2(2) XOR 80H;   /* - SIN(THET)*SIN(PHI)*/
CALL ADD(.TEMP1,.TEMP2,.TEMP4);
CALL MUL(.TEMP4,.TEMP3,.TEMP6); /* L* COS(THET+PHI)*/
CALL ADD(.TEMP6,.TEMP20,.TEMP5);
 CALL MUL(.TEMP20,.Z,.TEMP8);
CALL ADD(.TEMP8,.TEMP5,.TEMP6);  /* AZMIUTH LEAD */
 CALL FIX(.TEMP6,.ALEAD);
AA2:
RETURN;
 END GUNS;
/* SIMULATED SAMPLING LOOP */
 /* READ ALT */
 ALT= 100;
  /* READ TAS */
TAS= 500;
 CALL FLOAT(.TAS,.VF);
 /* READ BANK ANGLE */
THET=0; THET(1)=0; THET(2)=0;
 CALL COSSIN(.THET);
 /* READ CLOSING VELOCITEY */
 TAS=50;
 CALL FLOAT(.TAS,.VC);
```

```
/*- READ RANGE TO TGT */
DECLARE FEET ADDRESS;
FEET=1000;
CALL FLOAT(.FEET,.RANGE);
/* READ PITCH RATE */
RATE=120;
CALL FLOAT(.RATE,.AZR);
CALL DIV(.AZR,.THOU,.PR);
/* READ AZIMUTH RATE */
RATE=10;
DECLARE TEMR (3) BYTE;
CALL FLOAT(.RATE,.TEMR);
CALL DIV(.TEMR,.THOU,.AZR);
/*  READ ANGLE OF ATTACK IN MILS  */
TD=150;
CALL FLOAT(.TD,.AGF);
/* SAMPLE SWITCH */
CSSW=OFFH;
 CALL MUL(.AZR,.AZR,.TEMP1);
 CALL MUL(.PR,.PR,.TEMP2);
 CALL ADD(.TEMP1,.TEMP2,.TEMP3);
 CALL SQRT(.TEMP3,.TOTR);
 /*  TOTAL ANGULAR RATE = SQRT(PITCH RATE **2 +
 AZIMUTH RATE **2) */
CALL DIV(.PR,.TOTR,.SINP);
  CALL DIV(.AZR,.TOTR,.COSP);
 CALL MUL(.RHO(SHR(ALT,11)-1), .KDP,.KONS);
 CALL MUL(.VF,.FPS,.TEMP1);
AA4:
  IF (CSSW) THEN CALL GUNS;
  ELSE RETURN;
END SAMP;

 CALL SAMP;
 DECLARE JII ADDRESS INITIAL(10);
 DECLARE (XJJ,YJJ,ZJJ) (3) BYTE,(JX,JY,JZ) ADDRESS;
JX=85; JY=91; JZ=98;
 CALL FLOAT(.JX,.XJJ); CALL FLOAT(.JY,.YJJ);
AA3:
CALL FLOAT(.JZ,.ZJJ);
 AA6:
 DECLARE (DEN,TEM)(3)BYTE;
BB6:
 CALL FLOAT(.JII,.DEN);
 AA5:
  CALL DIV(.XJJ,.DEN,.TEM);
BB1:
 CALL LN(.TEM,.XJJ);
```

```
   BB2:
     CALL DIV(.YJJ,.DEN,.TEM);
   BB3:
    CALL LN(.TEM,.YJJ);
    BB4:
    CALL DIV(.ZJJ,.DEN,.TEM);
   BB5:
    CALL LN(.TEM,.ZJJ);
  AA1:
   JII=1;
   EOF
//PASS2.CARD DD *
$F=1 $G=1 $M=1 $Q=29 $B=7

//INTERP.CARD DD *
$F=1
LOAD 7 7.
$P=1
$MAX = 100000
DISPLAY SYMBOLS.

   REFER AA1,AA2,AA3,AA4,AA5,AA6.
   REFER BB1,BB2,BB3,BB4,BB5,BB6.
   BASE HEX.
   GO.
    TIME.
   GO.
    TIME.
    DIS MEM ALEAD.
   DIS MEM PLEAD.
$EOF
```

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An investigation of the use of micro computers to aid the pilot in the solution of the ballistics problem.